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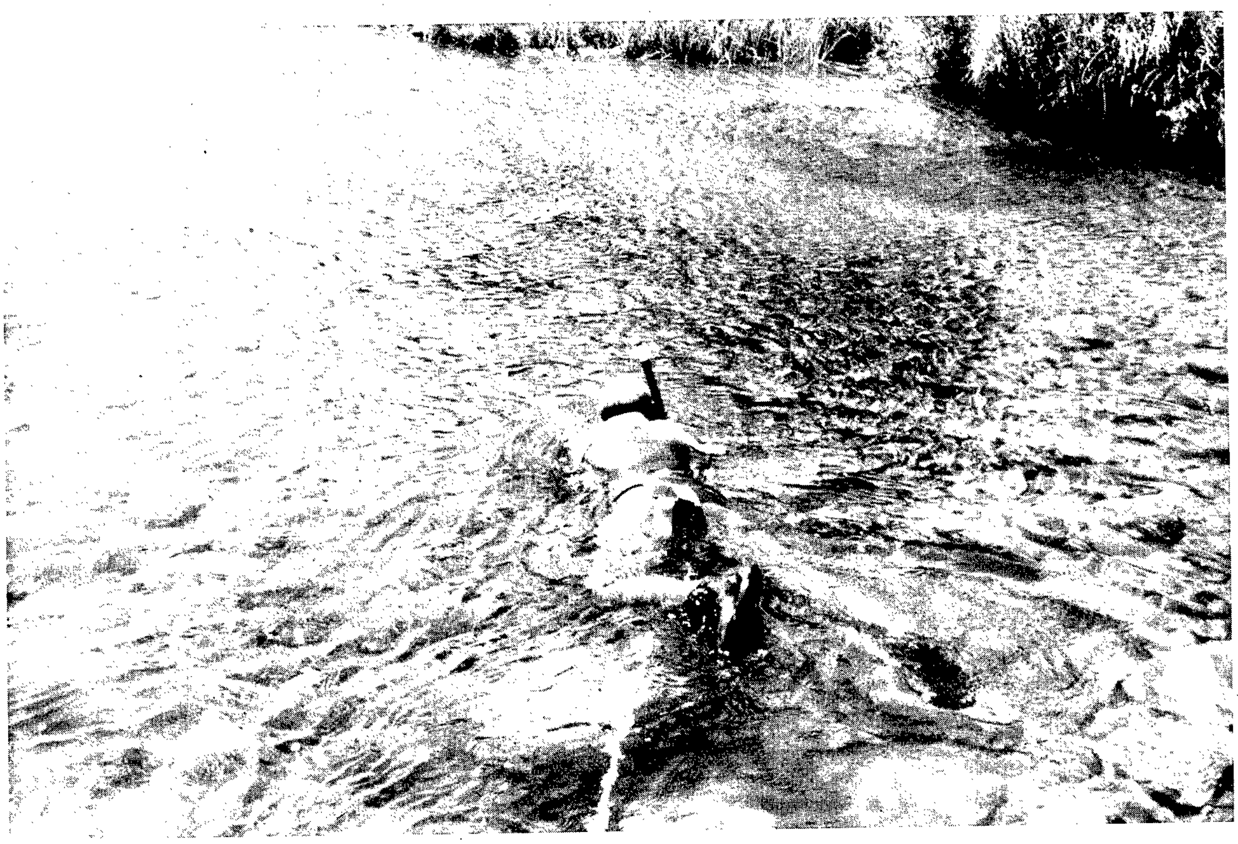
PROCEEDINGS OF A WORKSHOP ON THE DEVELOPMENT AND EVALUATION OF HABITAT SUITABILITY CRITERIA



Fish and Wildlife Service

U.S. Department of the Interior

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PROCEEDINGS OF A WORKSHOP ON THE DEVELOPMENT AND EVALUATION OF HABITAT SUITABILITY CRITERIA

A compilation of papers and discussions presented at
Colorado State University, Fort Collins, Colorado
December 8-12, 1986

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PREFACE

The development of reliable habitat suitability criteria is critical to the successful implementation of the Instream Flow Incremental Methodology (IFIM), or any other habitat based evaluation technology. It is also a fascinating topic of research, for several reasons. First, the "science" of habitat quantification is relatively young. Descriptions of habitat use and partitioning can be traced back to Darwin, if not further. Attempts to actually quantify habitat use can be found predominantly during the last two decades, with most of the activity occurring in about the last five years. Second, this work is challenging because we are usually working with fish or some other organism that lives out of sight in an environment that is foreign to humans. Most of the data collection techniques that have been developed for standard fisheries work are unsuited, without modification, for criteria development. These factors make anyone involved in this type of research a pioneer, of sorts. Pioneers often make new and wonderful discoveries, but they also sometimes get lost. In our opinion, however, there is an even more rewarding aspect to criteria development research. It seems that the field of biology has tended to become increasingly clinical over the years. Criteria development demands the unobtrusive observation of organisms in their natural environment, a fact that allows the biologist to be a naturalist and still get paid for it.

The relative youth and importance of habitat quantification have resulted in rapid advancements in the state of the art. The expansion of methods is vividly demonstrated simply by comparing the two Instream Flow Information Papers written on the subject in 1978 and in 1986. One of the missions of the Aquatic Systems Branch (formerly the Instream Flow Group) is to serve as a clearinghouse for new techniques and methods. In keeping with this role, a workshop was conducted during December 1986 to discuss current and newly evolving methods for developing and evaluating habitat suitability criteria. Participation in this workshop was largely by invitation only. The objective was to obtain insights into problems and possible solutions to criteria development, from the perspective of professionals closely involved with the subject. These proceedings of that workshop are intended to supplement the information contained in Instream Flow Information Paper 21, "Development and Evaluation of Habitat Suitability Criteria for Use in the Instream Flow Incremental Methodology."

The workshop was loosely arranged in five sessions, roughly following the outline of Information Paper 21. The first session dealt with various aspects of study design and how they can influence the outcome of a study. Session two investigated techniques for developing criteria from professional judgment, and some of the problems encountered when personal or agency prejudice enters the picture. Session three concentrated on field data collection procedures,

whereas session four examined methods of converting field data into curves. Field verification studies were discussed in session five.

Each presentation in the workshop was followed by a question and answer period of 15 to 30 minutes. These discussions were recorded, transcribed, and appended to the end of each paper in these proceedings. We have attempted to capture the essence of these discussions as accurately as possible, but hope that the reader can appreciate the difficulty in translating a free-ranging discussion (from a barely audible tape) to something that makes sense in print. These question and answer sessions constitute the peer review for each of the papers. This provides the reader with the unique opportunity to review the interactions between authors and reviewers.

The Aquatic Systems Branch intends to conduct similar workshops at approximately 3-year intervals. Questions regarding the contents of these proceedings or the status of future workshops should be directed to:

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No workshop of this type could be successful without the dedication and active participation of its contributors. We are grateful to the authors and other participants for their hard work in preparing these proceedings.

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CONTENTS

CONTENTS (Concluded)

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Most of the papers arrived on floppy disks from a dozen different kinds of word processors. Claud Alkire converted these to a format compatible with the word processing system used at the National Ecology Research Center, and Patricia Gillis hand-keyed the others.

Jennifer Shoemaker and Mary Sanz repaired and redrew the figures submitted by the authors so that they would fit in the text without loss of legibility.

HABITAT-USE GUILDS AND SELECTION OF INSTREAM FLOW TARGET SPECIES

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ABSTRACT

We grouped nine warmwater fishes (one to four lifestages) into habitat-use guilds on the basis of their microhabitat utilization patterns to assist in selecting target species for instream flow studies. Cluster analysis of depth, velocity, substrate, and cover utilization identified four primary habitat-use guilds, which were distinguished largely on the basis of velocity. Habitat suitability curves were developed for each species-lifestage and used in physical habitat simulation to determine relations between weighted usable area (WUA) and discharge for three streams in the upper James River basin, Virginia. Species within habitat-use guilds generally exhibited similar habitat response to discharge with the exception of some stream margin inhabitants and strongly cover-oriented species. Four types of habitat-discharge response curves, which were consistent across streams, were identified. In a Type I habitat response, WUA increased at a moderate rate and then decreased with a peak WUA near or above the average discharge. A Type II habitat response was similar but had a steeper ascending limb, and the peak WUA occurred at flows less than the average discharge. A Type III response, which was typical of pool inhabitants, showed a peak WUA at low flows and decreasing WUA with multiple peaks. Response curves for habitat generalists and some specialists exhibited relatively stable WUA over a range of flows. Target species and lifestages must be selected from habitat-use guilds to ensure that flow recommendations represent an appropriate compromise between the needs of fast-water and slack-water inhabitants.

INTRODUCTION

One of the most important but widely underemphasized steps in the instream flow incremental methodology (IFIM) process (Bovee 1982) is the selection of species to be used in the physical habitat simulation analysis (PHABSIM). Microhabitat preference criteria, which vary greatly among species and lifestages (Orth and Maughan 1982; Leonard et al. 1986; Bovee 1986), are the primary determinants of the relationship between weighted usable area and flow.

Some guidelines for selecting target species for habitat assessments have been published (HEP 101; Roberts and O'Neil 1985; Bovee 1986), but target species are often selected on the basis of narrow sport fish management objectives or availability of existing habitat suitability data. Some investigators have cautioned against use of habitat suitability criteria in areas outside their area of origin (Annear and Conder 1984; Moyle and Baltz 1985), and others have suggested that facultative riverine species (e.g., many sport fish) may be poor choices as target species because they are less sensitive to flow changes (Bovee 1986). Site-specific development of species habitat suitability criteria is generally recommended. Because flow recommendations may affect the entire fish assemblage, guidelines are needed to assist in selecting a limited number of target species that will ensure that flow recommendations represent an appropriate compromise for all species present.

We examined the microhabitat utilization patterns of warmwater fishes in the upper James River basin, Virginia, to develop guidelines for selecting target species. Our approach was to identify the habitat-use guilds of the assemblage of warmwater fish species present in four streams supporting smallmouth bass (Micropterus dolomieui) fisheries. Guild determination was based on microhabitat utilization data. We characterized the habitat (WUA) versus discharge relationship (habitat response) of each species/lifestage to determine if habitat response was consistent within habitat-use guilds and across study streams. Finally, we evaluated the importance of microhabitat variables in predicting (or discriminating) the type of habitat response a species/lifestage would exhibit. We anticipated that species using similar habitats would respond similarly to flow. If a species' habitat response could be predicted with some certainty on the basis of limited knowledge of habitat use, target species could be judiciously selected to include representatives of groups of species that respond similarly to flow.

STUDY AREA

The four study streams--Dunlap Creek, Craig Creek, Cowpasture River, and Maury River--are major tributaries of the upper James River basin draining the Ridge and Valley physiographic province of north-central Virginia (Figure 1).

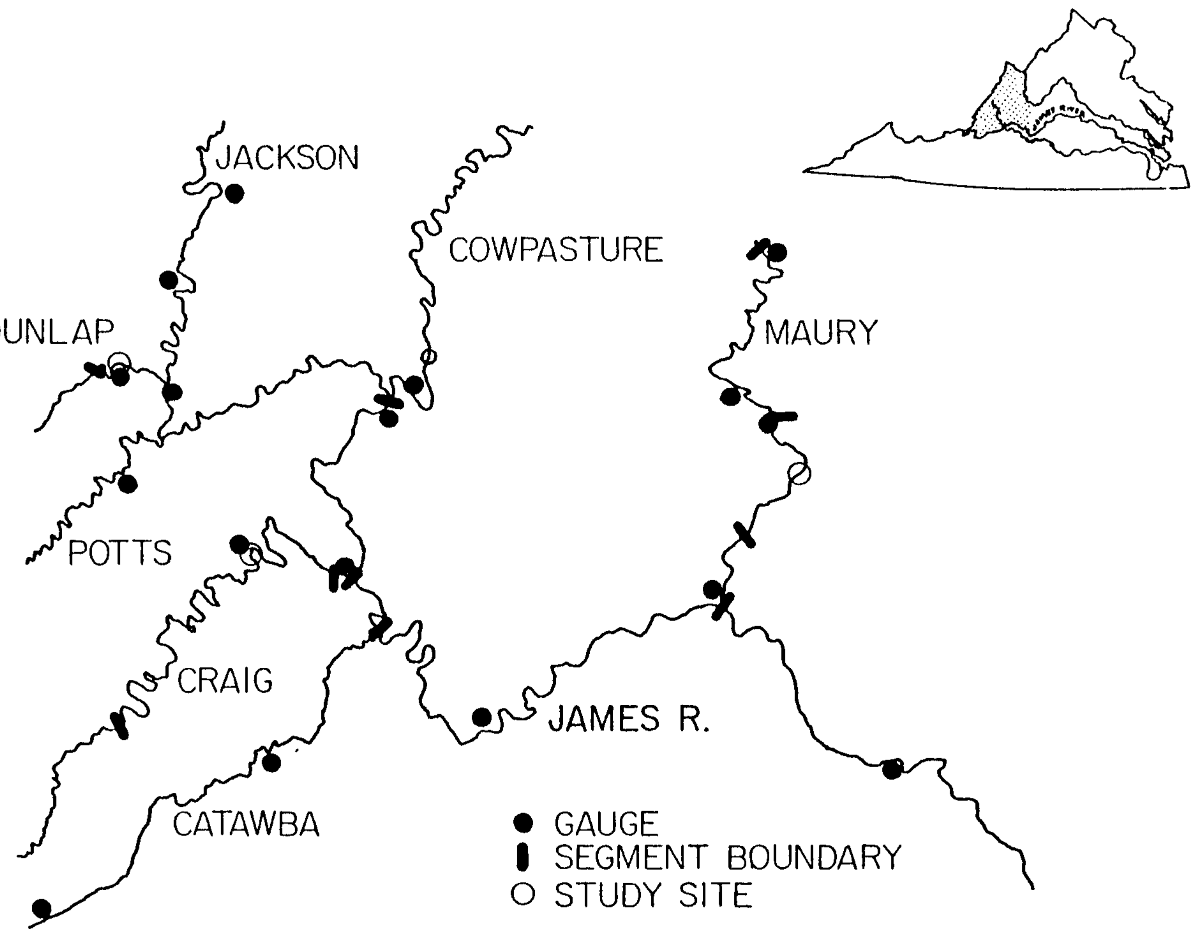

Figure 1. Study streams and locations of study sites on four streams in the upper James River basin, Virginia.

The three study sites selected for hydraulic and habitat simulation (Figure 1) represent a range of stream size; drainage areas range from 425 to 1,696 km^2 (Table 1). Seasonal discharge patterns are similar among streams (Leonard et al. 1986), but physical habitat features such as gradient, stream width, substrate, and dominant habitat types are variable (Table 1).

Fish assemblages in the upper James River basin were similar to those of other streams inhabited by smallmouth bass (Funk 1975). A total of 46 species were collected in the upper James River basin by Raleigh et al. (1974), but four species, usually cyprinids and centrarchids, typically composed the majority (50%-72%) of individuals at a site. We summarized their data for 18 mainstream and larger tributary sites to characterize the fish species composition and relative abundance in the study streams (Table 2).

Table 1. Physical characteristics and hydrologic statistics of the three study sites in the Upper James River basin, Virginia.

	Dunlap Creek near Covington, VA	Craig Creek at Parr, VA	Maury River near Buena Vista, VA
Drainage area (km^2)	425	852	1696
Mean daily discharge (m^3/sec)	4.7	10.9	18.5
Length of site (m)	308	237	759
Mean wetted width (m)	20.7	26.8	39.3
Stream gradient at site (m/km)	2.3	1.2	2.0
Habitat type (%)			
Riffle	29	20	16
Run	29	42	36
Transition	5	8	13
Pool	37	30	35
Dominant substrate types	Cobble Gravel Bedrock	Cobble Boulder Gravel	Cobble Bedrock Boulder

METHODS

HABITAT SUITABILITY CRITERIA

We developed habitat suitability criteria for fish species representing the major trophic and habitat guilds that compose the fish assemblage of typical smallmouth bass streams. These included riffle-dwelling herbivores (stonerollers) and insectivores (northern hog suckers, black jumprock), pool-dwelling insectivores (rock bass, smallmouth bass, redbreast sunfish), and run-dwelling insectivores (rosefin shiner, fallfish, chubs). One to four lifestages of each of the nine species were studied (Table 3).

Table 2. Top 20 of 46 fish species collected and their percent composition at 13 sites in the Upper James River basin (Raleigh et al. 1974).

Species	Percent	Species	Percent
*Bluehead chub	16	*Fallfish	2
*Redbreast sunfish	10	Margined madtom	2
*Rock bass	8	Fantail darter	2
Common shiner	6	White sucker	2
*Rosefin shiner	5	*Black jumprock	2
*Central stoneroller	5	Roanoke darter	2
*Bull chub	4	Torrent sucker	2
Cutlips minnow	3	Spottail shiner	2
Bluntnose minnow	3	Longnose dace	2
*Smallmouth bass	2	Swallowtail shiner	2

* This study.

Microhabitat utilization data were collected on various dates during the months of May through October, 1984 and 1985, in four streams: Dunlap Creek, Craig Creek, Maury River, and Cowpasture River. Most data were collected by direct underwater observation (snorkeling and scuba) (Campbell and Neuner 1986; Moyle and Baltz 1986). All observations were made between 1000 and 1500 hours in a full range of habitats with water clarity well exceeding minimum standards proposed by Hickman and Saylor (1984). Undisturbed fish were observed long enough to determine and record species, size class, focal point of microhabitat use, and cover type being utilized. Spawning microhabitat measurements were made at nests visually located from stream banks, boats, or by wading. Young-of-the-year (YOY) northern hog sucker occupied only very shallow areas and were located during nest surveys. Measurements of microhabitat utilized by spawning northern hog suckers were collected during May 1984 in the Little River, Virginia (Montgomery County). Spawning locations were determined by boat-electrofishing.

Table 3. Species selected for development of habitat suitability criteria and size ranges of each lifestage. Species and lifestage abbreviations are in parenthesis.

Species: Scientific name	Species: Common name	Lifestage (size range, millimeters): Young-of-year (YOY)	Juvenile (J)	Adult (A)
Catostomidae				
Hypentelium nigricans	Northern hog sucker (NH)	50	50-150	150
Moxostoma cervinum	Black jumprock (BJ)	50	50-150	150
Centrarchidae				
Ambloplites rupestris	Rock bass (RB)			
Lepomis auritus	Redbreast sunfish (RS)		Spawning only	
Micropterus dolomieui	Smallmouth bass (SB)	100	100-300	300
Cyprinidae				
Campostoma anomalum	Stoneroller (ST)	50	--	50
Nocomis spp.	Chub (CH)		Spawning only	
Notropis ardens	Rosefin shiner (RS)	50	--	50

At each fish or nest location, the following variables were measured: total water column depth (cm; metric wading rod), mean water column velocity (cm/s; pygmy current meter), dominant substrate type (modified Wentworth scale; Bovee and Cochnauer 1977), and dominant cover type. Cover types included no cover, instream objects (boulders, logs, etc., protruding from bottom ≥25 cm), overhead (objects within 1 m of water surface), undercut banks, ledges (bedrock irregularities ≥25 cm), and aquatic vegetation. Cover and substrate types were assigned ordinal codes for data analysis.

Two types of habitat suitability curves were developed. Utilization criteria (Bovee 1986) were developed for all spawning lifestages and YOY northern hog suckers by frequency analysis (Bovee and Cochnauer 1977). Preference criteria (corrected for habitat availability at the time of sampling) were developed for all other species lifestages according to Baldridge and Amos (1981). Habitat availability was determined by making measurements at 1-m intervals along transects within the stream reach snorkeled. Transects were selected at random until the number of availability measurements equalled or exceeded the number of fish habitat utilization measurements. Variables measured were identical to those described for fish and nest locations.

PHYSICAL HABITAT MODELING

We collected channel structure and hydraulic data for physical habitat simulation modeling following field procedures described by Bovee (1982) and Trihey and Wegner (1983). Within each study site, six to eight transects were

established at hydraulic controls and over major habitat types. Streambed elevations were measured and substrate type classified at 32-79 fixed intervals along each transect. Depth and mean column velocity were measured at these intervals for at least three different stream flows. At least three complete surveys of water surface elevations were made at each site during steady flow as required for the water surface profile (WSP) hydraulic model (Bovee and Milhous 1978).

The WSP and IFG4 hydraulic models were used in combination because shifts in velocity distributions at different flows or nonlinearity of the stage-discharge relationship occurred at all sites. Flows to be simulated were divided into ranges. Each range of flows was simulated separately, with stages calculated by the IFG4 or WSP models. Velocities were predicted with Manning's equation calibrated with velocities measured at the nearest flow. We simulated flows from 10% to 200% of the average discharge for all streams, and hydraulic simulation diagnostics indicated that simulation quality was good to fair for the range of flows reported here (Leonard et al. 1986).

Hydraulic simulation and microhabitat preference criteria were combined in the HABTAT model (Bovee 1982) to produce weighted usable area estimates for each lifestage for all simulated flows. The composite weighting factor for suitability, Si, was obtained using the multiplicative aggregation function: Si = Sv • Sd • Ss • Sc, where Sv, Sd, Ss, and Sc are suitability weighting factors for velocity, depth, substrate, and cover.

DATA ANALYSIS

We used cluster analysis to first identify groups of species/lifestages that utilized similar habitats (habitat-use guilds). The mean depth, velocity, substrate, and cover values for each lifestage were standarized and used in average-linkage cluster analysis (Romesburg 1984). Similarity of habitat response within habitat-use guilds was evaluated both visually, based on the shape of the WUA versus discharge relationships, and by cluster analysis of the standardized WUA values. After assigning each species to a unique habitat-response type, we used canonical discriminant analysis (Dillon and Goldstein 1984) to evaluate the importance of the microhabitat variables in discriminating the type of habitat response a species was likely to exhibit.

RESULTS AND DISCUSSION

HABITAT-USE GUILDS

A total of 1,146 microhabitat utilization measurements were collected during 1984 and 1985, representing the microhabitat use of 4,581 individuals of 18 species-lifestage combinations. The use of depth, velocity, substrate, and cover by fishes of the upper James River indicates the presence and use of a wide range of habitats and substantial overlap in microhabitat use among species (Table 4).

Table 4. Summary of microhabitat measurements for eight species of upper James River basin fishes. Individual substrate and cover types with a frequency of use ≥25% are listed. Bd = bedrock, Fn = fines, Gr = gravel, Co = cobble, Bo = boulder, I = instream object, L = ledge, and N = no cover.

Lifestage[a]	Mean water depth (cm)	Mean column velocity (cm/sec)	Dominant substrate	Substrate score	Dominant cover	Cover score
Northern hog sucker						
Y	24.2	14.8	Gr, Fn	1.8	N	1.0
S	40.5	64.1	Gr, Co	2.6	N	2.3
Black jumprock						
J	35.2	31.2	Co	1.9	I, N	4.9
A	58.3	37.3	Co, Bd	2.7	N, I	3.3
Rock bass						
A	122.1	4.6	Bd, Fn	0.5	I, L	4.7
S	35.9	1.8	Co	2.9	N	1.0
Redbreast sunfish						
S	59.5	1.0	Fn, Gr	1.5	N	2.6
Smallmouth bass						
Y	82.4	9.9	Co, Bd	2.1	I, N	3.4
J	87.4	18.0	Co, Bo, Bd	2.4	I, N	3.9
A	108.3	14.1	Bd, Co	2.0	I, L, N	3.9
S	44.4	5.8	Co, Bo	2.5	I, N	4.1
Stoneroller						
A	40.3	34.0	Co	2.9	I, N	3.8
Chub						
Y	61.5	1.4	Fn, Co	1.6	N	1.6
J	80.2	12.8	Fn, Co	1.8	N, I	2.5
A	82.1	20.7	Co	2.0	N, I	3.2
S	34.2	22.3	Co	2.9	N	1.4
Rosefin shiner						
Y	77.1	11.5	Bd, Co	1.4	N, I	2.8
A	64.8	19.4	Co	2.5	N, I	2.7

[a]A = adult, J = juvenile, S = spawning, and Y = young-of-year.

Cluster analysis of the standardized microhabitat values identified four habitat-use guilds (Figure 2). We interpreted these groups qualitatively, based on microhabitat values (Table 4) and field observations, as follows.

Juvenile and adult black jumprock, adult stonerollers, and spawning northern hog suckers constitute the riffle guild. These species utilized areas of moderate to fast current [>30 cm/sec mean column velocity (MCV)] of shallow depth (<60 cm) and cobble/gravel substrates, and either used instream objects as a velocity shelter or no cover (Table 4). Although spawning northern hog suckers did not cluster with the riffle group, their habitat use was most similar to riffle inhabitants, except for their use of faster velocities.

Members of the run guild include YOY and adult rosefin shiners, YOY and juvenile smallmouth bass, and juvenile and adult chubs (Figure 2). All used relatively deep (>60 cm), moderate to slow velocities (<21 cm/sec MCV) over a variety of substrate types. Based on field observations, some of these species were always closely associated with the riffle-pool transition (rosefin shiners), while others received intermediate habitat values by using a wide range of habitats, but primarily the riffle-pool transition zone.

Pool species, adult smallmouth and rock bass, inhabited deep (>100 cm), slow (<15 cm/sec MCV) areas with primarily bedrock or fine substrates and were closely associated with cover objects (instream objects, ledges).

The stream margin guild comprises species that used generally shallow slow areas near the periphery of the stream. Two subgroups are apparent within this guild. Spawning rock bass, smallmouth bass, redbreast sunfish, and YOY chub inhabited very slow (<6 cm/sec MCV), shallow areas, while YOY northern hog suckers and spawning chubs frequently used areas of moderate velocities (14-22 cm/sec MCV).

HABITAT-RESPONSE RELATIONSHIPS

Four general types of habitat-response curves were found (see Figure 3):

(I) WUA increases at a moderately rapid rate then decreases (unimodal), with a broad peak at or above the average discharge (AD);

(II) WUA increases rapidly (steep ascending limb) then decreases (unimodal), with narrower peak WUA generally occurring at flows less than AD, with moderate amount of WUA at lowest flows;

(III) peak WUA values at low flows, monotonically decreasing with discharge; and

(IV) WUA changes little, decreases at highest discharge.

These groupings are subjective (visually assigned), and the habitat responses of species can occur along a continuum defined by these types.

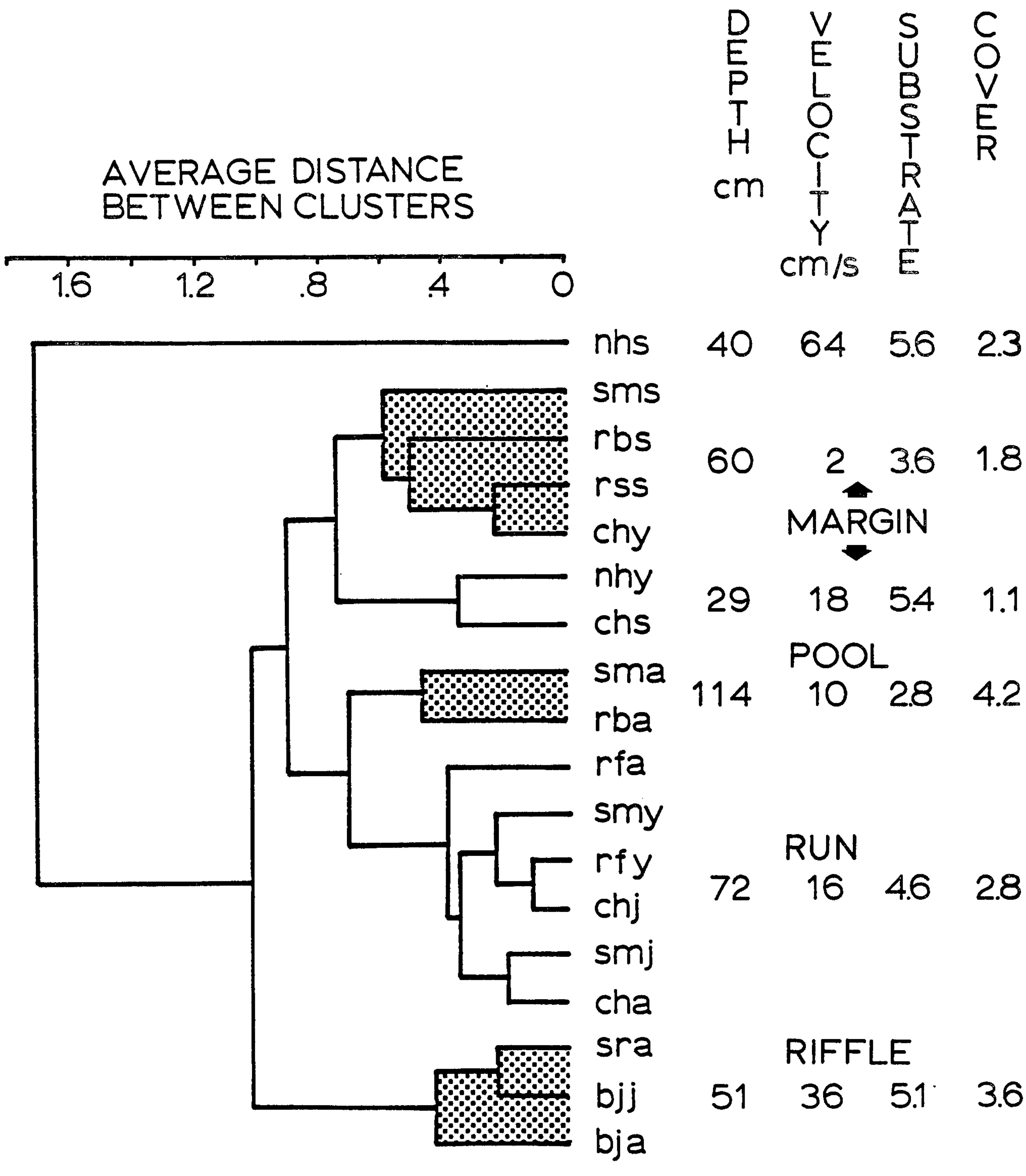

Figure 2. Dendogram showing the similarity of microhabitat use by lifestages of eight species of warmwater fishes based on cluster analysis. Four major habitat-use guilds are indicated, and mean values of microhabitat variables are provided for guilds or subguilds.

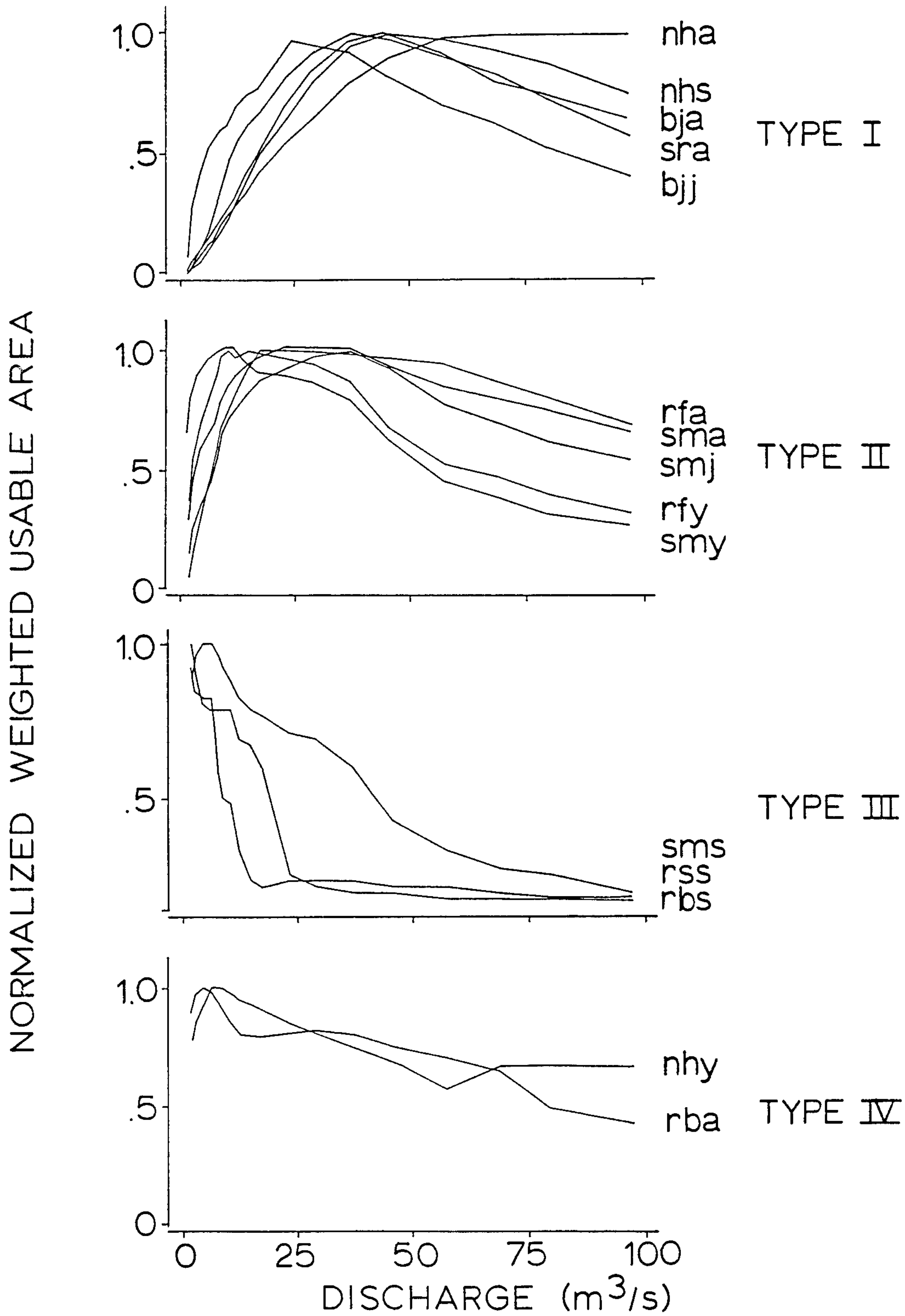

Figure 3. Normalized weighted usable area versus discharge relationships grouped by habitat-response type for lifestage of eight warmwater fish species for the Dunlap Creek site.

Having characterized the types of habitat responses, we examined within-guild and across-stream variation in habitat response (Table 5). All species within habitat-use guilds do not exhibit the same habitat response type. However, some important generalizations are possible.

Riffle and run species typically exhibit unimodal (Type I and II) habitat responses (Table 5). Increasing flows yield more habitat in the preferred range of species with moderate to high velocity preferences.

Flows above some optimum result in habitat loss, generally due to velocities above these species' preferred range (Figure 3). With few exceptions, riffle and run species exhibit Type I and Type II habitat responses, respectively. Run species have moderate velocity preferences and exhibit steeper ascending and descending limbs of the WUA curve (Figure 3), because velocity more quickly enters their preferred range as flows increase. For riffle species, riffle areas must first attain suitable depths, then velocities must enter preferred ranges, before optimum habitat area is reached. Therefore, ascending limbs are less steep.

Margin species exhibited a variety of habitat responses (Table 5). However, the centrarchid spawner subgroup (spawning rock bass, redbreast sunfish, and smallmouth bass) (Figure 2) exhibited a Type III response. The preferred habitat of this group--slow, moderate to shallow depth areas--is at a maximum at the lowest flows because pools and runs maintain much of their depth and surface area at low flows, and velocities are low or zero. Loss of habitat occurs with increasing discharge, as velocities increase, and many low-flow pool areas become run habitat. Type III responses often show secondary peaks or stairstep patterns as areas in the stream channel with suitable substrate cover become wetted.

The remaining margin species use moderate velocity, shallow areas and exhibit little or no preference for cover (Figure 2). Spawning chubs exhibited a distinct preference for riffle margins and show a Type II response for the reasons given for riffle species. Northern hog sucker YOY used the periphery of the stream (shallow and slow), and suitable stream edge habitat is apparently available over a wide range of flows.

The two pool species, rock bass and smallmouth bass, did not respond similarly to flow (Table 5). Rock bass exhibited different habitat responses in each stream. We think that this variability is due to the strong affinity of rock bass for cover and variation in the distribution and abundance of cover in the three study streams. With some exceptions, the type of habitat response exhibited by a species was consistent across the range of stream size. There is preliminary indication (rock bass), however, that a strong affinity for cover may result in exceptions to this generalization.

CONTRIBUTION OF MICROHABITAT VARIABLES IN DETERMINING RESPONSE TYPE

An important component of selecting target species is the ability to predict the type of habitat response a species will exhibit based on limited information about the species' habitat preference. Each species was

Table 5. Habitat-response types exhibited by lifestage of eight fish species in three upper James River tributaries. Species with similar habitat-response types, as identified in cluster analysis, are connected (Arabic numerals).

HABITAT-USE GUILD		HABITAT-RESPONSE TYPE DUNLAP	CRAIG	MAURY
RIFFLE				
Jumprock	a	I	I	I
Jumprock	j	II	II	II
Stoneroller	a	I	I	I
Hogsucker	s	I	I	I
RUN				
Rosefin	a	I	I	II
Rosefin	y	II	II	II
Smallmouth	y	II	II	II
Smallmouth	j	II	II	II
POOL				
Rock bass	a	IV	III	II
Smallmouth	a	II	II	II
MARGIN				
Chub	s	II	II	I
Hogsucker	y	IV	IV	IV
Rock bass	s	III	III	III
Redbreast	s	III	III	III
Smallmouth	s	III	III	III

objectively placed into a mutually exclusive habitat-response group, based on cluster analysis of the normalized WUA-versus-discharge relationship (Table 5). Using stepwise discriminant analysis (Dillon and Goldstein 1984), we evaluated the contribution of the predictor variables (means of depth, velocity, substrate, and cover utilized) in determining the type of habitat response a species exhibited. Cluster analysis identified four groupings of habitat responses (indicated in Arabic numerals; Table 5) similar to the habitat response types subjectively defined. A species was assigned to a group (1, 2, 3, or 4) if it clustered with that group in two or three of the streams

simulated. For example, adult stonerollers were assigned to habitat response group 1.

Stepwise discriminant analysis showed that the order of importance of microhabitat variables in discriminating habitat-response types was: velocity, depth, cover, substrate. However, only velocity was statistically significant ($P < 0.05$).

IMPLICATIONS FOR SELECTING TARGET SPECIES

Based on physical microhabitat analysis of these warmwater streams, it appears that physical habitat may not be a limiting factor for lifestages of some species. Species with Type IV responses have WUA indices that are insensitive to flow; such species may be common in warmwater streams.

The microhabitat needs of these species may be inadequately described by the variables used, or physical (temperature, water quality) or ecological (predation, competition) factors may limit these species (Orth 1987). These species are of low priority as target species because they will provide little information in establishing appropriate flow regimes.

It may seem intuitive that species with the most narrow microhabitat preferences would be most sensitive to flow, and the opposite would be true of habitat generalists. However, WUA for some species that preferred narrow ranges of microhabitat variables was insensitive to flow changes (e.g., northern hog sucker YOY). Therefore, an alternative approach for selecting target species is needed.

Target species should be selected considering the profound effect on the resulting flow recommendation. It is possible to "stack the deck," either intentionally or accidentally, in favor of a specific flow recommendation. Consider the following hypothetical assemblage of four possible target species (Figure 4), exhibiting three different habitat-response types (Types I, II, and III). Considering all species, and using a habitat optimization procedure (dark line) (Loar and Sale 1981; Bovee 1982; Sale et al. 1982; Leonard et al. 1986), the recommended optimum flow is about 65 cfs (Figure 4). However, if no riffle species had been selected (the two Type I curves), the resulting flow recommendation would be only 18 cfs.

The effect of target species selection, illustrated above, should be an explicit part of negotiations when State and Federal resource agencies and developers convene to scope an instream flow study. Resource agencies must critically examine their rationale for proposing only pool-dwelling or facultative riverine species as the primary candidates for target species. These species often show Type III habitat responses (Leonard et al. 1986) and would result in lower recommended flows unsuitable for many other species.

When selecting target species, one should attempt to anticipate the type of response a species will exhibit, so that representatives of the major response groups can be incorporated into the study. The results of this study suggest that, in these warmwater streams, the key variable in predicting

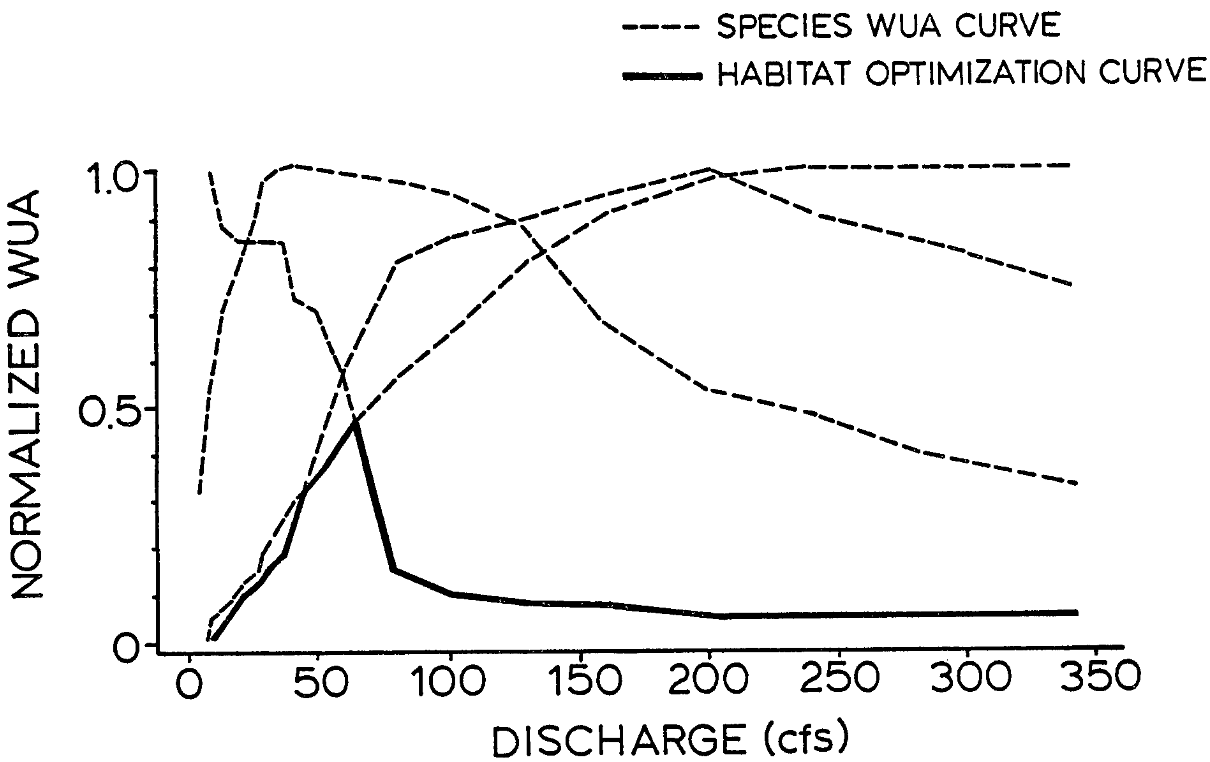

Figure 4. Hypothetical weighted usable area versus discharge relationships for four species, with results of habitat optimization procedure indicated.

species response to flow changes is velocity. The shape of the habitat-response curve is a function of the species' habitat preferences and reflects the interaction between hydraulic variables and channel structure as discharge increases. Velocity is more affected by a given change in flow than are other hydraulic variables (Kraft 1972; Williams and Winget 1979). The optimum habitat range for many species is most closely associated with their velocity preferences. There is some indication, however, that this relationship may not hold true for species strongly associated with cover. Channel shape and distribution of cover and their relationship to wetted stream bottom may be more important determinants. Thus, the importance of microhabitat variables in predicting habitat response may change with region and fish species present.

GUIDELINES FOR SELECTING TARGET SPECIES

The ultimate objective of instream flow recommendations should be to maintain the integrity of the aquatic biota (Moyle and Baltz 1985). Target species should be selected to ensure a compromise between the needs of fast-water and slack-water inhabitants. We suggest the following general approach.

1. Rank all common species and their lifestages by velocity preference. If limited information is available about the microhabitat preferences of some species, use the judgment of a local ichthyological expert to accomplish this step. Include fishes and invertebrates.

2. Select species from the extremes of the velocity preference continuum--inhabitants of swift (riffle) and slow (pool or slow margin) areas.

3. Incorporate more than one species from the habitat-use extremes. More than one species is suggested because of within-guild variability in habitat response.

Bovee (1986) identified two classification systems for use in selecting target species, based on (1) fisheries management objectives, and (2) species' adaptions to riverine environments. We have discussed an approach based on the latter and have presented evidence supporting the utility in using a guilding approach to select target species. The approach we have outlined is functionally similar to selecting species representative of the major microhabitat types (e.g., main channel riffles, pools, backwaters), but attempts to generalize about how species in these microhabitats respond to flow. The approach is similar to Martin and Campbell's (1953) in using current velocity as the primary demarcation between guilds, but in the future, may be extended to incorporate vertical distribution (benthic vs. upper water column, nose velocities) and a more rigorous examination of the effect of cover orientation.

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QUESTION AND ANSWER SESSION

Paul Leonard

Li: Reflecting back on the habitat utilization or habitat response curves, it appeared that you were getting different responses, with use guilds I and II switching back and forth. I suggest that because those types were using comparable areal distributions, the switching may reflect that their habitats are very similar. My second point concerns the rock bass, which you found in deep pools and in association with type II species. I suggest that because they are a slow velocity species, the smaller streams may have slower velocities in general.

Leonard: With respect to your first question, I would agree. Type one and type two species used somewhat similar habitat types and had similar distributions in the streams although type one species velocity preferences were higher. Consequently, their habitat response curves were similar and influenced in subtle ways by factors such as gradient and channel morphology in the different streams. Your second point is well taken and correctly identifies problems with using habitat suitability criteria in a stream of a different size than in which they were developed. We couldn't develop criteria for each different stream size, so we used the mid-sized streams and extrapolated up and down. There are some problems associated with this because a fish species habitat preference is surely somewhat different in a small stream versus a large river.

Bovee: In your experience with margin species, do they relate to the edge of the water or the edge of the channel? In other words, are they reacting to the cover conditions at the edge of the stream, or the hydraulic conditions at the edge of the water?

Leonard: I think it is the hydraulic conditions that they are keying on. But the relative importance of these is species and lifestage specific. Distinguishing the relative importance of cover versus hydraulic conditions may be difficult at the stream margin because stream edge may itself be a form of cover or escape from predation. Some species showed no affinity for cover when undisturbed. They occurred in open stream margin areas and the data show no great affinity for cover. When disturbed, the fish generally used escape cover. For large fish this meant moving into deeper water or into a cover object but for some small fish this meant moving into shallow water. Smallmouth bass often pick stream margin areas in back of obstructions that act as velocity shelters. This may be an adaptation which affords protection to eggs and larvae for times when flow increases. Regardless, certain hydraulic conditions at the stream edge seem important to some lifestages, even when structural cover is absent.

Jean Caldwell: You mentioned how you resolved the result of your analyses, showing that type IV species were not affected by velocity, but cover was very

important. Yet you conducted the second analysis using velocity even though you suspected that you had one whole set that didn't fit the analysis.

Leonard: Let me clarify by reiterating some major points relating to your question. We first grouped species according to their habitat response types, that is, the way their available habitat changed with discharge. The rock bass, a slow-water, strongly cover-oriented species was unique in that it showed a different habitat-response type in each stream, and we guess that this was due to it's exceptionally strong cover orientation, not that it was not paying attention to velocity. In the second analysis, we used a statistical technique, canonical discriminant analysis, to objectively determine the relative importance of the habitat variables in determining the habitat response type a species would be likely to exhibit. So the second analysis did not proceed under assumptions about velocity, rather it established that velocity was the most useful variable in predicting the type of habitat response a species would likely exhibit.

Hanson: Do you have the same assemblages of fishes in all those streams, or is it possible that some reversals in guild association might be due to different groups having one species more associated with one assemblage in a particular stream, and more associated with a different assemblage in another stream?

Leonard: If I understand your question correctly, you are asking if different species compositions in the study streams affected the habitat utilization of a given species. We cannot answer that question based on the analysis I've presented because we pooled the microhabitat utilization from all study streams to derive our habitat suitability criteria. However, anecdotal evidence from snorkeling observations suggest that what you are saying could happen, especially where the species interaction is predation. Presence of predators definitely appeared to restrict some species habitat use. Other species interactions actually appeared beneficial or at least noncompetitive. For example, we observed groups of stonerollers, chubs, and black jumprock which formed roving, foraging schools.

A STATISTICAL APPROACH TO DETERMINING SAMPLE SIZE FOR SPECIES HABITAT PREFERENCE CURVES

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Pick up almost any textbook on statistics, thumb over to the chapter on sample size determination and the leading paragraph may read something like this: "Data collection costs money. If the sample size is too large, time and money are wasted. Conversely, it is wasteful if the sample is too small, because inadequate information has been purchased for the time and effort expended" (Ott 1984). Indeed, an adequate sample size is important in the study of any natural population. In instream flow studies, this is especially true for the development of species habitat preference curves. Preference curves are often viewed as the "soft underbelly" by critics who wish to attack an instream flow study. Because of its importance, we would like to probe deeper into the question of sample size as it relates to the development of preference curves for instream flow analysis. We want to focus attention on the question: How many data are enough?

We are presently involved in an instream flow study on the Verde River in Arizona in which we are trying to predict impacts from proposed stream diversions. We are developing preference curves for a number of fish species and verifying existing curves for others. The question of how many data points are needed to develop preference curves becomes very important for the two reasons cited by Ott (1984), time and money.

MONEY

The costs associated with collecting habitat use data for developing preference curves include equipment, travel, and personnel. An additional expense is the expert identification of larval fish, and this expertise may or may not be available in-house. There are other expenses that could be

included; however, for ease of illustration we will only consider costs for personnel (salary + per diem) and larval fish identification. To date, an estimated $28,000 has been spent on personnel costs and $2,500 on larval fish samples. We normally use a crew of three people to collect habitat use data (shocker, netter, and recorder), which costs an average of $540/collecting day. It becomes obvious that data collection is an expensive activity.

TIME

Every project has a schedule and deadlines. It is important to judge how "good" your preference curves are because in all likelihood you will not have enough time to collect the number of data points recommended for all species and lifestages. Given this reality you may be faced with the decision to: (1) be satisfied with the data you have, or (2) slip the deadline in order to collect more data. The decision to increase the amount of time devoted to data collection for preference curves may be made for several reasons. For example, in the case of the spawning or larval life stages you may simply have to wait until the next spring to resume data collection. In addition to normal annual cycles, some species may have unpredictable population fluctuations that preclude adequate sampling in one or several years. This problem may be seen in species that have sharp swings in populations, and you may have to wait until an "up" year to collect the data needed for that species. However, you could feel better about making either choice 1 or 2 if you had an idea of how "good" the curves are that were developed on limited data.

A third concern, which may outweigh the first two, is damage to the resource, i.e., needlessly killing or injuring fish. The methods used to collect habitat use data don't usually cause much fish mortality. However, several species we have worked with are on State and Federal endangered species lists, and their populations may already be in trouble. These species should not be subjected to unnecessary collecting. In simple terms, if 50 data points are adequate to determine a species' habitat preference then obtaining 150 data points means 100 points were collected unnecessarily.

Now that we have demonstrated some reasons for answering the question of how much data are enough to build preference curves, let's examine the sample size guidelines established by the Fish and Wildlife Service's, Instream Flow Group (Fort Collins, Colorado). Sample size recommendations are mentioned in several Instream Flow Group publications (Bovee 1982; Nelson 1984; FWS 1985). All of these papers recommend that a minimum of 150 data points per lifestage are necessary to develop habitat preference curves. Keep in mind that these data points are observations and not individual fish. For example, a single electrofishing sample that contains five carp is one observation (i.e., one data point). Nelson (1984) states that sample size depends on variance and the desired degree of accuracy. He goes on to state that experience has shown that 150-200 data points are needed. However, based on experience, we think that for many of the species and their lifestages, fixed recommendations may be an oversimplification.

The recommended number of data points needed to develop a preference curve should be based on statistics that describe the variance of the population and not on a fixed number (i.e., 150). A species that shows little variance (tightly clustered) will need fewer measurements to describe it than one with large variance (loosely clustered).

Now we come to the question of which parameter should the sample size statistics be based on: depth, velocity, cover, or substrate. Of these four choices, depth and velocity are best because they are objective, continuous variables. The choice between depth and velocity depends on the variance of each. We usually select the one with the greatest variance because it yields the largest estimate of sample size.

SAMPLE SIZE FORMULAS

Which statistical formula for estimating sample size is best? We investigated several sample size formulas. Although they all are related, we caution researchers to inspect any formula carefully before applying it. Most rely on an estimate of variance in some form and relate this to some other statistic. Keep in mind that the relationship between these statistics is critical when selecting a method. For example, we examined a sample size formula used in the Habitat Evaluation Procedures (HEP) ESM 102 Manual (FWS 1980).

$$n = \left(\frac{Zc}{D}\right) \cdot \left(\frac{s}{X}\right) \tag{1}$$

where n = recommended sample size

Zc = Z score at selected confidence interval

D = the relative precision

X = the sample mean

s = sample standard deviation

Close examination reveals that this formula is based on a ratio between the standard deviation and the mean. In some combinations of life stages and measured parameters, e.g., abundance of larval fish versus water velocity, the variance is extremely small, but because the mean is close to zero, the ratio between the mean and standard deviation is inordinately large. This can result in an extreme overestimation of sample size. This formula fails to take into account the units of measure (depth to the nearest 0.1 ft and velocity to the nearest ft/sec).

The sample size formula that seems to fit our needs the best is found in Eason et al. (1980):

$$n = Zc^2 \bullet \frac{s^2}{a^2} \tag{2}$$

where n = recommended sample size

Zc = Z score at selected confidence interval

s = sample standard deviation

a = accuracy (units ± the true mean)

This formula uses a Z score, which is essentially a critical value of the Student's t-distribution with infinite degrees of freedom. We have modified this formula by replacing the Z score with a t-table value for the presample size we wish to use. In our example, t = 2.201 (based on 11 degrees of freedom and a 95 percent confidence interval) versus Zc = 1.96 (based on infinite degrees of freedom and a 95 percent confidence interval). This makes our final sample size estimate larger than that proposed by Eason (1980). Based on this modification, the sample size formula used in this study was:

$$n = tc\ [p-1]^2\ \frac{(s^2)}{(a^2)} \tag{3}$$

where n = recommended sample size

$tc\ [p-1]$ = critical value derived from a Student's t-distribution

p = presample size

and s and a have been previously defined.

After a sample size formula is selected, a presample (p) must be taken to estimate the population variance. We used 12 data points to estimate the population variance and selected a pool species, carp (Cyprinus carpio), and a shallow water species, spikedace (Meda fulgida), for comparison. We used a random number generator to select 12 depth and velocity measurements for each species. Based on this information, we determined the sample size necessary to describe each population at a 95 percent confidence interval ±0.1 ft or ft/sec for depth and velocity, respectively (Table 1).

Table 2 shows a comparison of sample size estimates for larval spikedace and Sonoran sucker (Catostomus insignis) based on a presample. Larval Sonoran suckers were used because no larval carp were collected. Larval fish data provided habitat use curves that were tightly clustered, narrow, and nearly identical (Figure 1). Statistics confirm what is intuitively obvious from the curves; namely, fewer data points are needed to describe larvae than adults.

Table 1. Sample size estimates for adult carp and spikedace based on a presample collected on the Verde River in Arizona during the spring and summer of 1986. Estimated sample sizes are given for both depth and velocity at 95 percent confidence interval ±0.1 ft or ft/sec for depth and velocity, respectively.

Carp		Spikedace	
Velocity	Depth	Velocity	Depth
0.0	1.0	0.5	0.1
0.1	3.0	0.3	0.4
0.0	5.5	0.1	0.5
0.7	2.1	0.1	0.6
0.2	1.9	1.0	1.0
0.3	1.7	1.3	0.5
0.2	1.4	1.4	0.5
0.2	2.0	1.6	1.0
0.4	2.3	1.6	1.0
0.1	1.8	1.6	0.8
0.3	1.2	1.6	0.7
0.3	0.7	1.9	1.0

	Carp	Meda
Presample size	p=12	p=12
Presample Standard Deviation		
Velocity	s=.19	s=.66
Depth	s=1.25	s=.29
Sample Size Estimate		
Velocity	n=18	n=211
Depth	n=757	n=42

Example, based on carp, is for depth at 95 percent confidence level ±.1 ft

$$n = 2.201^2 \frac{(1.25)^2}{(.1)^2} = 757$$

We have now answered the question of how many data are enough. Now let's examine the question of how good are the data. Table 1 shows that we need 757 adult carp data points to be 95 percent confident that our sample mean is ±0.1 cfs of the true mean. Carp were suprisingly hard to come by, and at this time we have 57 adult data points, a long way from 757 (or even 150). We wonder how "good" this curve is based on the limited data. The sample size formula can help answer the question. First, we compute the standard deviation (1.19) for depth for the entire sample of 57 adult carp data points. Plugging this information into the formula, we find that a sample size of 568 is adequate, if we are also willing to settle for a 90 percent confidence interval. Besides lowering the confidence interval, we can also lower the specified accuracy level. The present sample size estimate is large because we specified an accuracy level of ±0.1 ft the true mean. Based on our knowledge of this species, however, is depth so critical that we need to measure it with this precision? In this study, adult carp curves were plotted at 0.5 ft depth increments. If an accuracy level of ±.25 ft is used then the mean will fall within the increment used to build the curve. Substituting this information into the formula, we find that a sample size of only 64 is necessary to obtain an estimate that is ±0.25 ft of the true mean at a 90 percent confidence interval. We now have a general idea of the strength of the curve.

Table 2. Sample size estimates for larvel spikedace and Sonoran sucker based on a presample collected on the Verde River in Arizona during 1986. Sample size estimates are given for both depth and velocity at 95 percent confidence interval ±0.1 ft or ft/sec for depth and velocity, respectively.

Spikedace		Sonoran sucker	
Depth	Velocity	Depth	Velocity
0.7	0.0	1.0	0.6
0.6	0.2	1.2	0.0
0.7	0.0	0.8	0.0
0.2	0.0	0.6	0.2
0.6	0.0	0.3	0.1
0.5	0.0	0.3	0.1
0.1	0.0	0.6	0.2
0.2	0.0	0.5	0.3
0.1	0.1	0.6	0.1
0.2	0.0	0.6	0.0
0.3	0.0	0.9	0.1
0.3	0.0	0.5	0.1

	Spikedace	Sonoran Sucker
Presample size	p=12	p=12
Presample Standard Deviation		
Velocity	s=.06	s=.17
Depth	s=.23	s=.27
Sample Size Estimate		
Velocity	n=2	n=15
Depth	n=26	n=35

Example, based on spikedace, is for depth at 95 percent confidence level and ±.1 ft

$$n = 2.201^2 \frac{(.23)^2}{(.1)^2} = 26$$

In summary, the objective of this paper was not to solve the sample size problem, but rather to point out an area that needs refinement, to offer some suggestions, and, hopefully, to get some minds working on it.

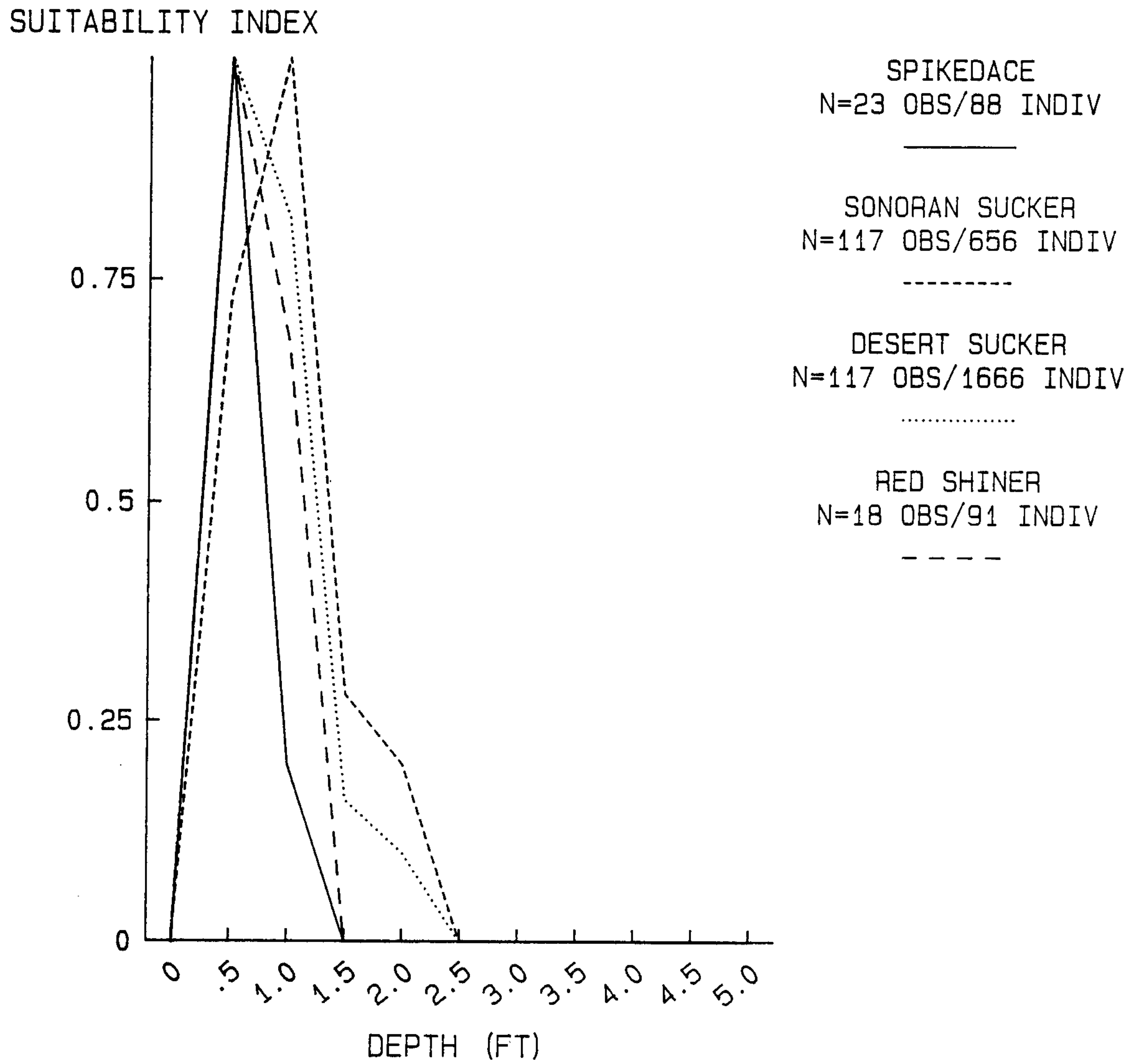

Figure 1. Depth suitability index curves for four species of larval fish. Data were collected during 1986 from the Verde River in Arizona.

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QUESTION AND ANSWER SESSION

Paul Barrett

Lifton: One thing that I have done in the past is to use a Monte Carlo technique and make various random draws of the habitat measurments from the total population of data. Using different draws with different sample sizes you look for stability of the curve. If the curve tends to stabilize at sample sizes smaller than the total data population, then you probably have enough data. If the curve tends to wander as you approach your entire data set, then you probably have a problem.

Barrett: How do you determine if you are stabilized?

Lifton: You can look at the shape of the curve or you can actually measure it by using a T test fit.

Barrett: The T test assumes a normal distribution.

Lifton: That is true, but we use the T test as a measure of the heteroscedasticity.

Barrett: We are also comparing curves from different geographical areas using a Kolmogoroff-Smirnoff test to compare distributions. That might be another way to test for sample size convergence using the Monte Carlo technique.

Campbell: I have one comment. We have noticed that in developing preference criteria, the variability of habitat availability data is much greater than the utilization data and typically requires samples sizes twice as large.

Barrett: We haven't been able to conduct a preference analysis on the Verde River data yet. It is important, however, to know how sensitive the final curves will be to the availability data. We may want to conduct a similar test on preference curves just to make sure that our curves are all right, even though our utilization data base appears to be satisfactory from the outset. One of the things that I didn't point out was that we used the 57 carp data, ran the formula and found out that we needed 64. But that shows that according to this technique, we were close to our required sample size. This is not an absolute requirement, but it will give you a better idea of how much data you need.

Lifton: This is just a guess on my part. It seems like most of these statistical tests are geared towards the mean of the distribution whereas we see many of the differences in the curves at the tail of the distributions.

Barrett: Yes, that was my second point.

Leonard: How do these considerations apply to developing availability functions based on synthesized data such as PHABSIM simulations?

Barrett: That is a good question and I don't have an answer for it yet. In the end, these are all just tools. They still require that we apply some biological judgment.

IFIM - MICROHABITAT CRITERIA DEVELOPMENT: DATA POOLING CONSIDERATIONS

by

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ABSTRACT

Habitat preference criteria (used with the Instream Flow Incremental Methodology developed by the Cooperative Instream Flow Service Group of the United States Fish and Wildlife Service, Ft. Collins, Colorado) are developed from field data by comparing frequency analysis of used and available habitat. Hydraulic simulation models and point use measurements of depth and velocity for rainbow trout (Salmo gairdneri) fry, adult, and juvenile and Rocky Mountain whitefish (Prosopium williamsoni) juvenile and adult were used to determine the degree of use and availability of two microhabitat parameters--flow depth and velocity. Considerations for pooling data from several sites were accommodated through study design and several data pooling techniques.

INTRODUCTION

Pooling data refers to the practice of combining data sets collected from different reaches and at different times into a common data base. If you wish to adequately describe an animal's behavior (in terms of microhabitat criteria) over a wide range of naturally occurring flow conditions, you must develop one final criteria function from several sets of data. Data that have been collected from several reaches in the same stream, from different streams, under different streamflow conditions, or with different gear can, and do, create data pooling problems. The purpose of this paper is to discuss data pooling considerations. Examples are provided from two separate microhabitat criteria studies conducted by the Alberta Fish and Wildlife Division. This paper presents the outcome of those two studies and sampling strategies outlined in Bovee (1986).

CASE STUDIES

STUDY I: SHEEP RIVER TRIBUTARIES - 1983

In 1983, an Instream Flow Incremental Methodology (IFIM) study was conducted by the Fish and Wildlife Division on several creeks within a watershed located in the foothills of the Rockies southwest of Calgary (Figure 1). Part of that study included the collection of microhabitat criteria for rainbow trout (Salmo gairdneri) fry (0-4 weeks).

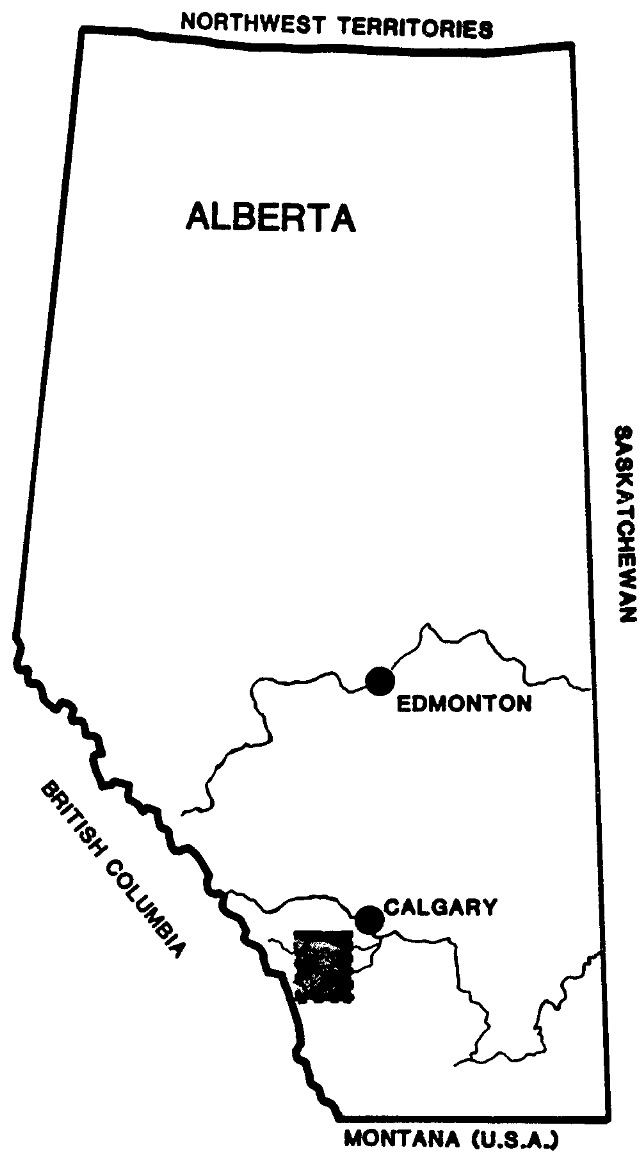

Figure 1. Study I - location of study area.

The four creeks where data were collected were Ware Creek, which flows into Threepoint, Threepoint Creek itself, which flows into the Sheep River, and Pekisko and Sullivan creeks, both of which flow into the Highwood River (Figure 2). The Sheep River eventually joins the Highwood River, which in turn flows into the Bow River downstream of the City of Calgary. All four of the creeks are used as spawning areas by adult rainbow trout that migrate up from the Bow River. Once the eggs hatch, fry use the streams, to a certain extent, as rearing or nursery areas. IFIM hydraulic data had been previously collected on Threepoint Creek, and one of the objectives of this study was to develop site-specific biological criteria instead of using those presented in Bovee (1978). Several methods were used to collect data from as many areas of the stream as possible. The data collection techniques used were direct observation from the bank, electrofishing, minnow traps, and seine hauls. It was assumed that the combination of these techniques would provide a good sample of the population.

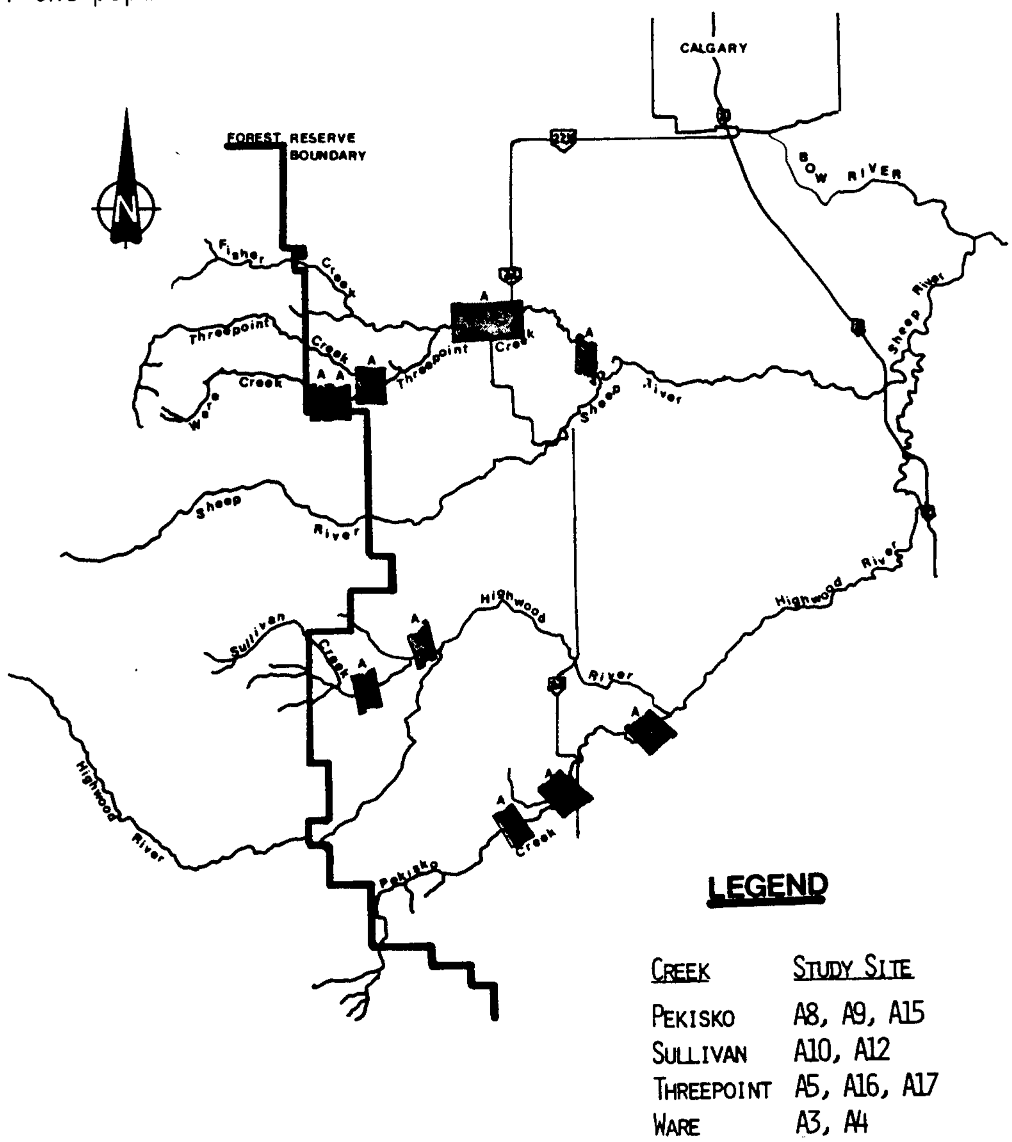

Figure 2. Study I - study sites.

Histograms were developed and, through frequency analysis and basic biostatistics, final curves were developed.

It was decided to collect data not only for the habitat being used but also to determine the relative availability of that habitat to the species and life stage in question. The result of combining the habitat use and availability data is referred to as the preference function, or Category III criteria (Figure 3). It became apparent that the many bits of information collected from several locations on four different streams, using several different data collection techniques, could not be simply combined or directly added. How do you combine data collected at one site using one technique, for example, direct observation, with a second technique, such as electrofishing? The two data sets cannot be added directly, since each method has a specific efficiency factor and, in theory, if added directly, data collected using one method could significantly bias the results. This bias can be attributed to the efficiency of the technique or type of habitat sampled. An example of this is shown in Figure 4.

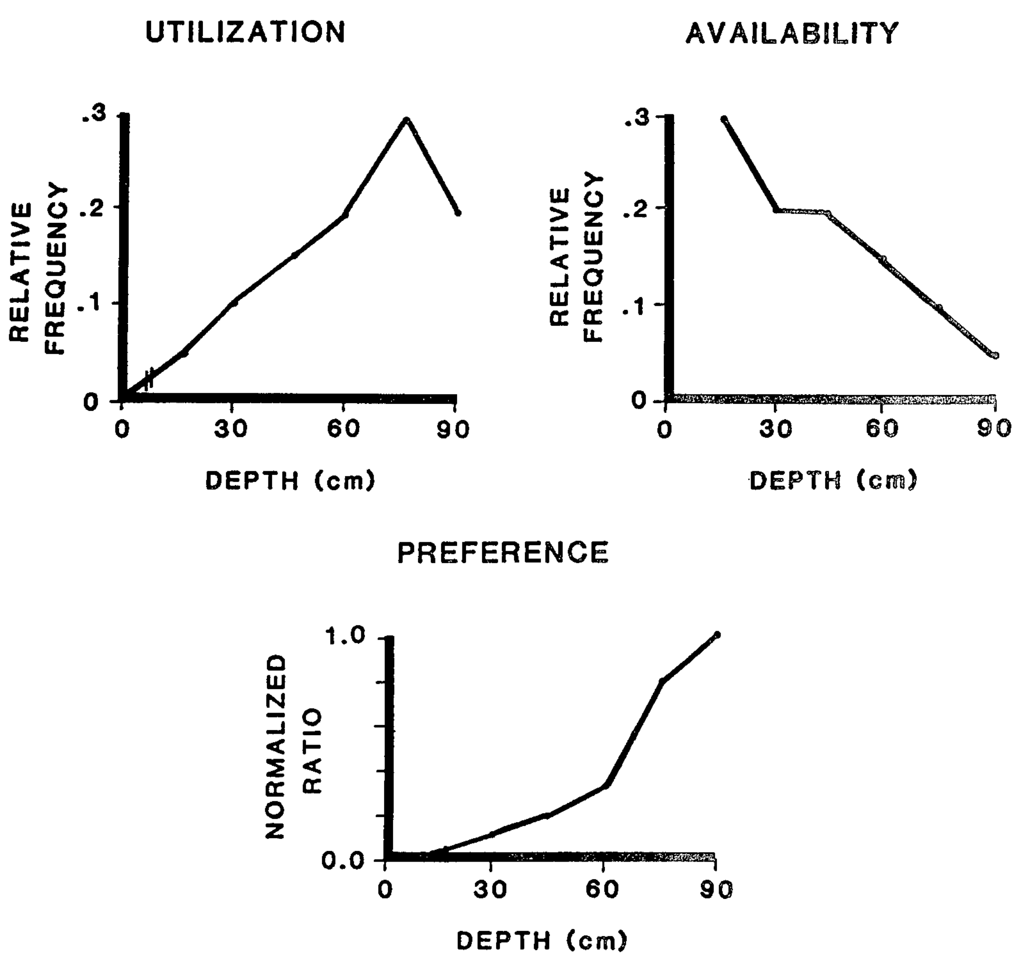

Figure 3. Comparison of utilization, availability, and preference curves derived from histogram analysis (from Bovee 1986).

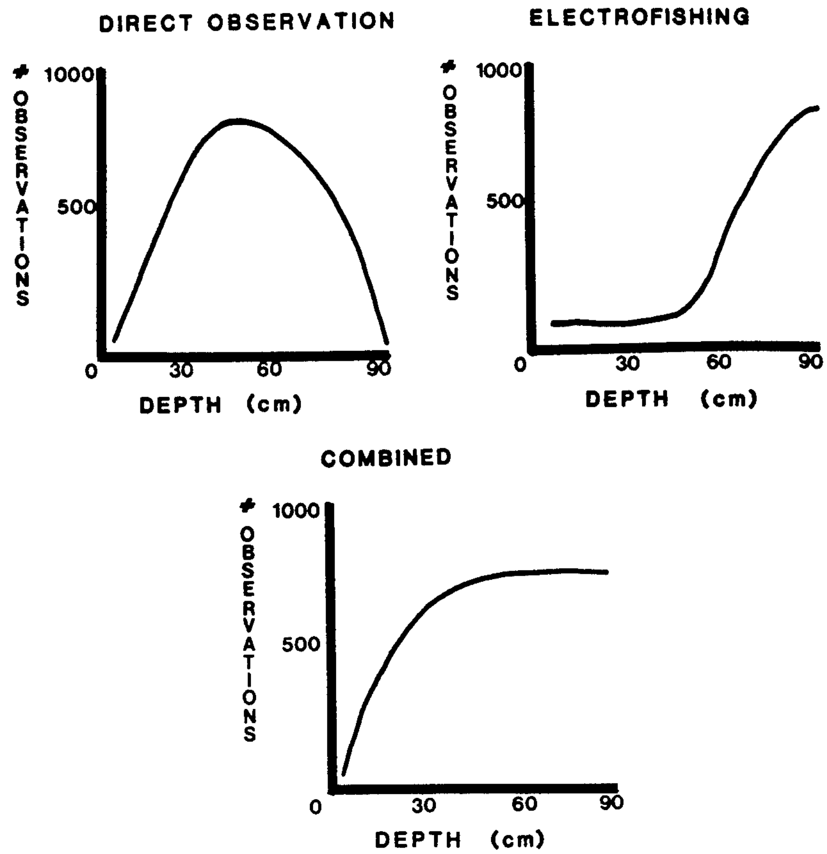

Figure 4. Combination of two data sets using two data collection techniques.

Another consideration was the influence or effect of the characteristics of each study site, and whether the data should be weighted before combining. For example, if Site 2 was three times as large as Site 1, then for each interval, the number of observations from Site 2 should be weighted by a factor of 3 before being added to the Site 1 data (Figure 5). This is a consideration when developing Category III criteria, but not when developing Category II (use) criteria. In the latter instance, data sets are directly additive.

The outcome of this study resulted in use curves for the four creeks (Figure 6), one curve for the watershed, and a preference curve for Study Site A17 (an existing IFIM hydraulic study site) on Threepoint Creek.

The differences in final PHABSIM output using different sets of depth and velocity criteria are shown in Figure 7. The two use curves, one from data collected solely on Threepoint Creek and one from data collected on all four creeks, and the preference criteria developed from Study Site A17 resulted in Weighted Usable Area vs. Discharge (WUA vs. Q) curves with the same mode and similar shapes. The only difference between these curves was magnitude. The criteria from Bovee (1978) resulted in a differently shaped curve with a different mode (Locke 1986).

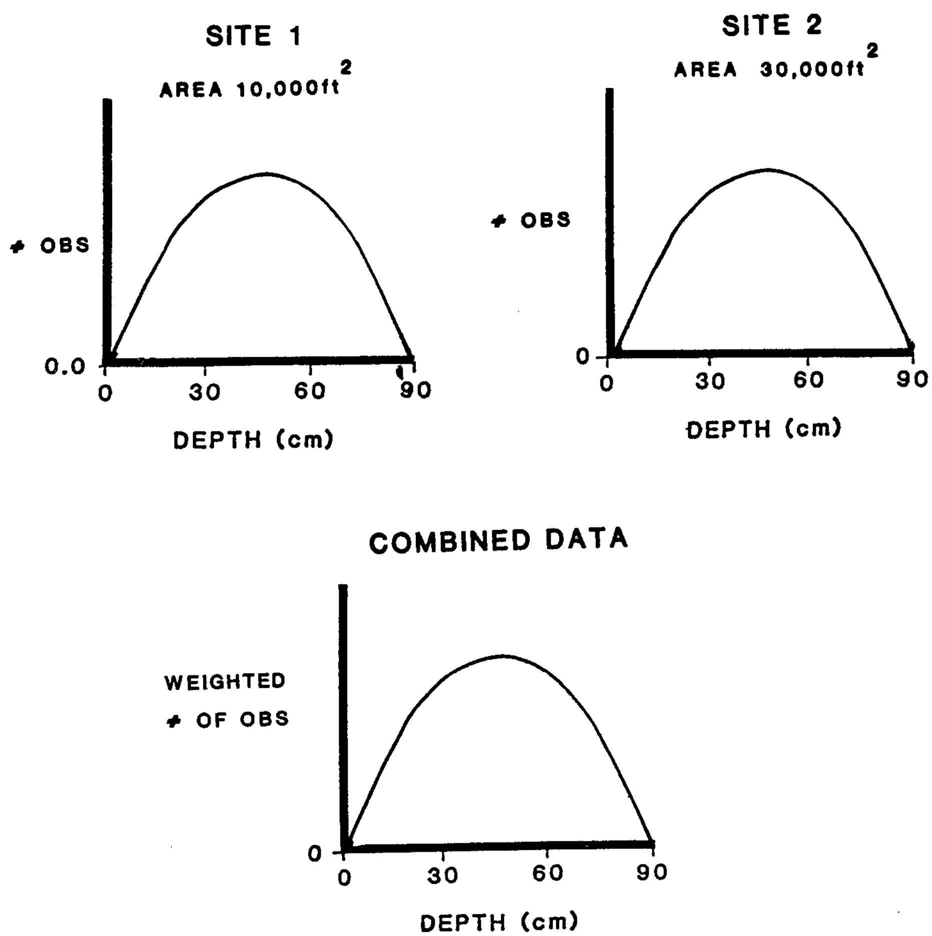

Figure 5. Example of weighting data to account for study site area.

STUDY II: SHEEP RIVER - 1985

In 1985, the Fish and Wildlife Division carried out another IFIM study, this time on the Sheep River. The Sheep River has year-round resident rainbow trout, bull trout, brown trout, and Rocky Mountain whitefish. There is also some mainstem spawning of Bow River rainbow trout (Figure 8). One of the objectives of this study was to develop Category III criteria for the juvenile and adult life stages of rainbow trout and Rocky Mountain whitefish. Before going into the field it was necessary to determine how data should be collected to avoid data pooling problems. It was also decided to collect data over a range of conditions, since it was considered desirable to measure the animal's response to a normal range of flow conditions rather than at just one point in time.

The data collection technique selected was direct underwater observation using SCUBA gear. It was felt that the targeted life stages and river in question allowed for the use of this technique in all habitat types. By using one data collection technique, the need to weight each data set based on

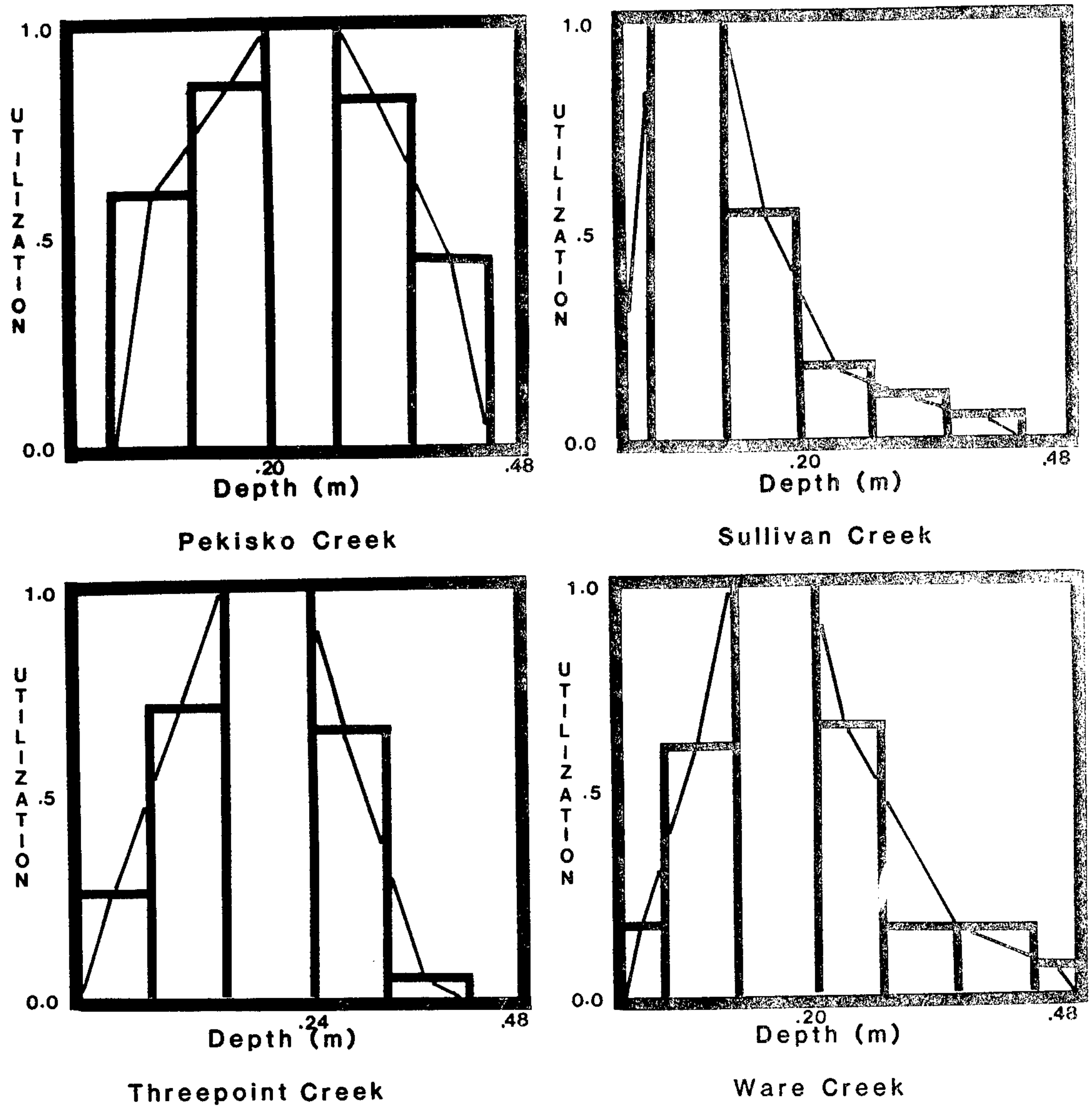

Figure 6. Depth utilization curves for rainbow trout fry, 1983.

efficiency of the technique was eliminated. The next consideration was the pooling of data sets, with the concept of available habitat factored in. The data collecting options were as follows:

(1) collect several replicates of data within the IFIM hydraulic study site (so the available habitat could be generated by running PHABSIM for each day of recorded use data);

(2) select several sites within the segment and, for each set of use data, collect the corresponding available habitat data; or

(3) collect data at several sites and within the IFIM hydraulic site.

For this study data were collected within the IFIM hydraulic site, since this considerably reduced field time, and available habitat could be generated using PHABSIM mapping.

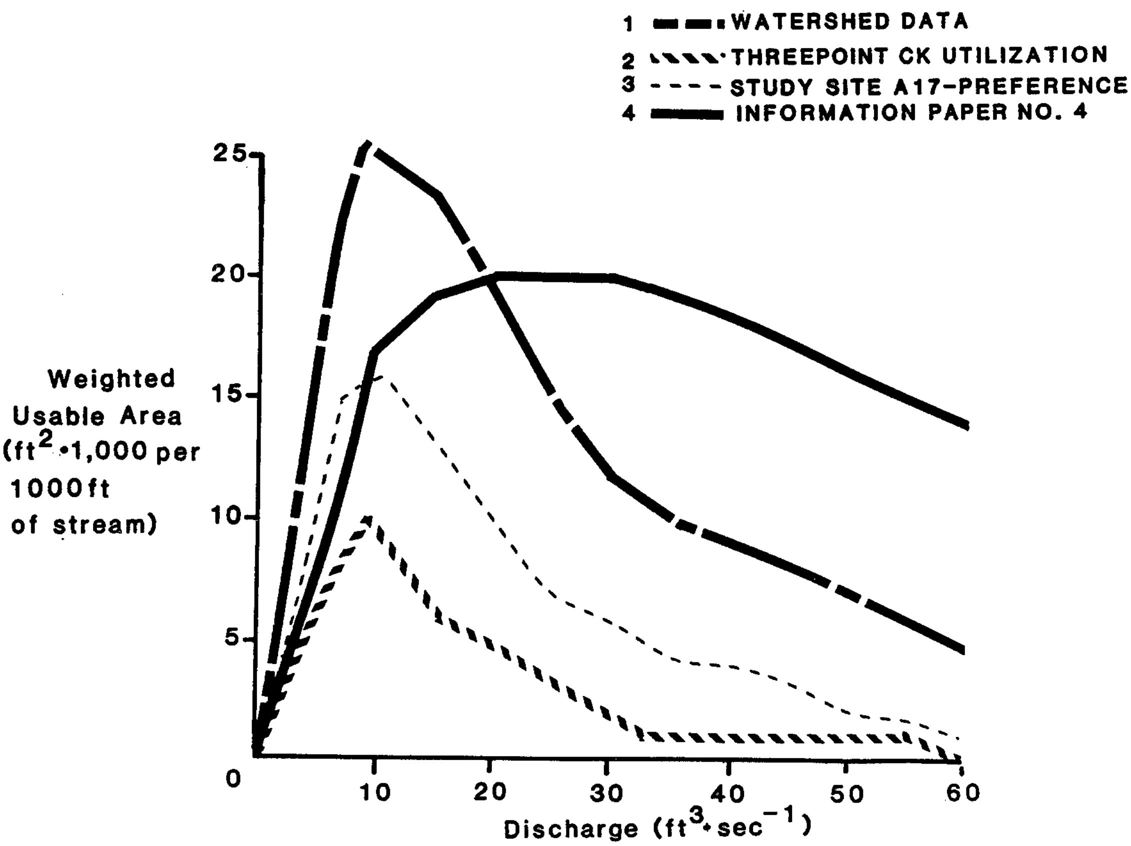

Figure 7. Differences in PHABSIM output for rainbow trout fry using three variations of data pooling and curves from Information Paper 4 (Bovee 1978).

Use data were collected each day, and discharge, which was the same each day, was recorded. This meant the available habitat was the same for each use data set. The data sets could then be directly added and subsequently divided by the available habitat (Figure 9). Other reasons why the use data were directly additive or of equal weight include the following:

(1) the same technique, direct underwater observation by SCUBA diver, was used each time;

(2) the same time was allocted for data collection each day; and

(3) the area of the study site was constant (Locke 1986).

An example of a final Category III curve is shown in Figure 10.

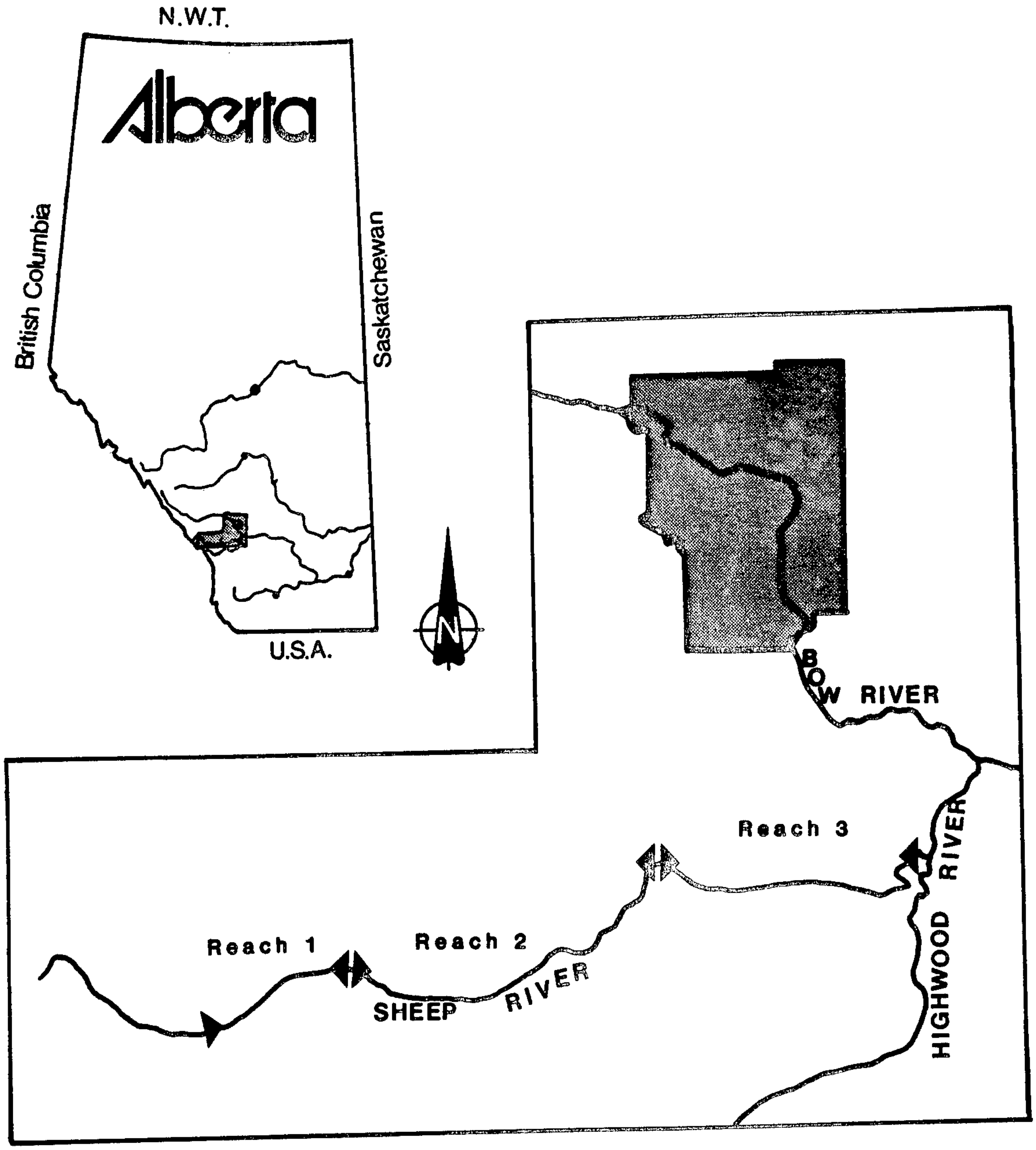

Figure 8. Study II - study area.

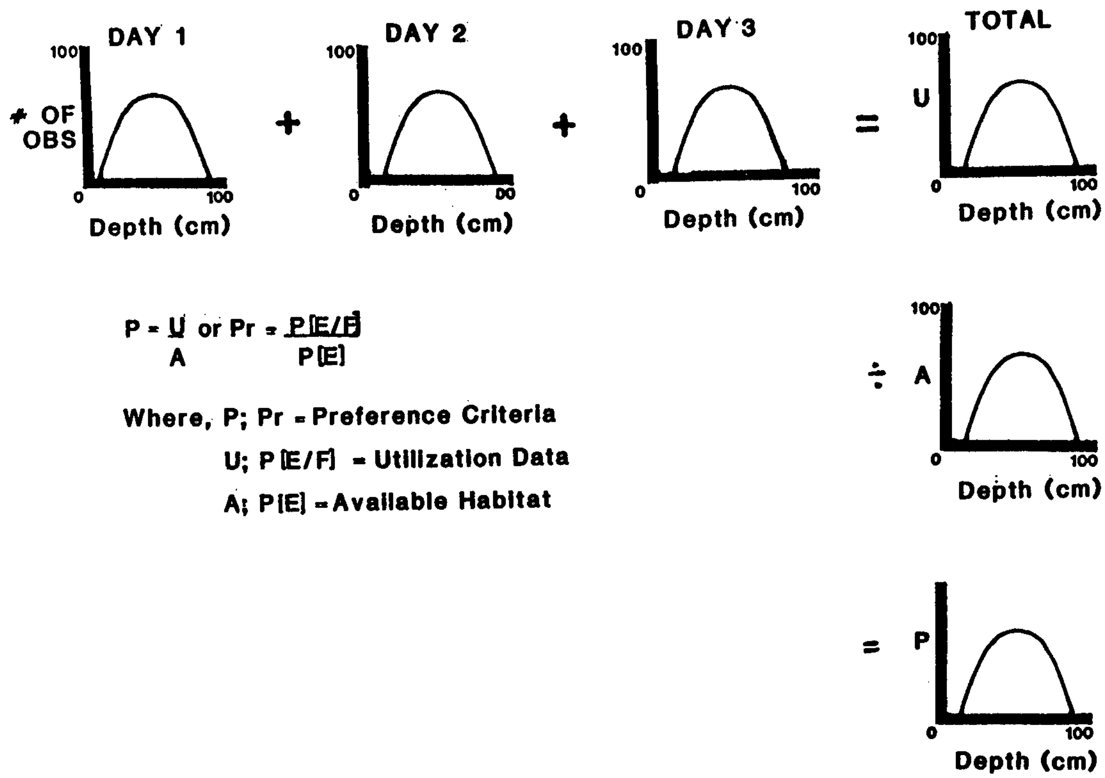

Figure 9. Pooling utilization data when the available habitat remains constant.

REASONS FOR POOLING DATA SETS

With any IFIM study where the collection of microhabitat data is an objective, the pooling of two or more data sets is inevitable. If it were possible to collect a sufficient set of data from one site, in one day, using one technique, it would be questionable whether the data collected from one point in time and space truly reflects the behavior of an animal in a wide range of normally occurring flow conditions. It is often argued that such data are not a true reflection, and it is necessary to collect data over time, at least one full field season.

Another reason for pooling data is the likelihood that insufficient data will be collected to satisfy sample size requirements because of the variation in relative abundance of the life stages and species being studied. Several sets of data are necessary to obtain a reasonable sample of the population.

It is desirable to collect data from several different sites on a stream or on several streams within a basin. This ensures data are collected from

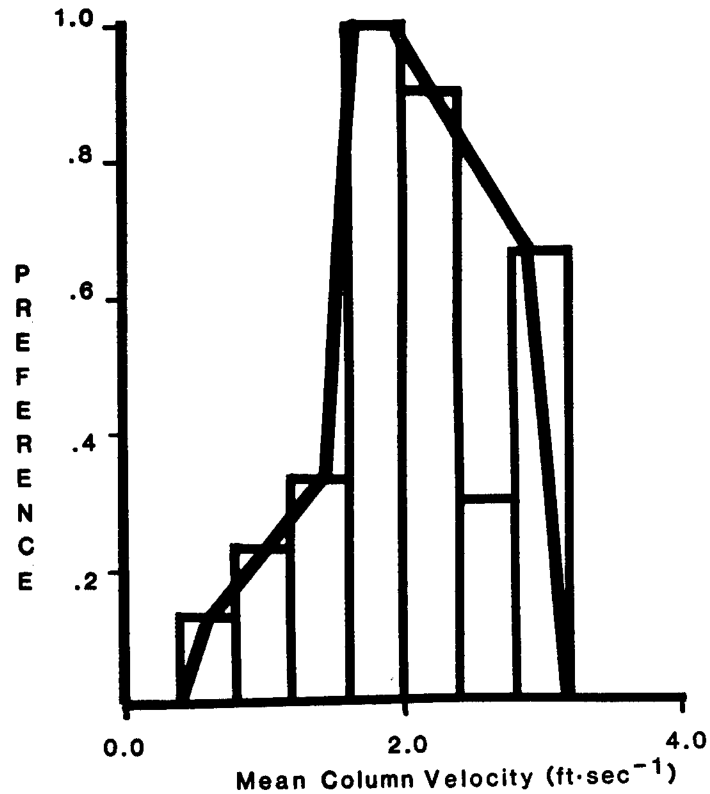

Figure 10. Mean column velocity preference curve of Rocky Mountain whitefish adults in Sheep River, 1985.

all habitat types and that the criteria are representative of all streams and can be used for any IFIM study within the basin. This precludes the costly development of microhabitat criteria each time an IFIM study is conducted on a different stream.

Depending on the life stage and species, one collection technique may not be sufficient to sample all habitat types within a study site. Recently hatched fry that inhabit both the spaces between rocks in the riffle areas as well as deep quiet pools are an example. In the riffle areas, electrofishing may be the only technique that can be used, whereas in the pools, electrofishing may be used, but direct observation is likely to be a better method. When two techniques are used, the two data sets will have to be combined using some type of weighting factor to account for differences in efficiencies of the techniques.

POOLING DATA

THEORETICAL WORST CASE SCENARIO

Let's examine a theoretical worst case scenario where data were collected using several collection techniques at several locations and at several

different times. In Figure 11, the difficulty in combining these data sets is apparent. The task of deriving the final curve is tedious. One approach is to first combine the data sets for Day 1 at Site 1. The raw frequencies can be combined, provided a weighting factor is applied to each sampling technique to account for the difference in efficiency. This process is then repeated for Site 2 and so on until all the sites are completed. The next step is to combine the data sets from each site. Again, a weighting factor must be applied to each data set before data sets can be combined, to account for such factors as the difference in area between sites and total time spent collecting data. The final values for each day can then be combined and are directly additive. Similarly, the columns or site totals could be calculated and summed to derive the final curve. If you are developing use criteria, you can either add the raw frequencies and normalize the curve, or normalize the curves along each step of the process and then combine them. If you are developing preference criteria, you must generate a normalized curve for each day and site. This is done by dividing the use data by the available habitat for each interval. When developing preference data you cannot combine raw use data from one site or one day with another day or site, since the amount of habitat used at Site 1 has no relation to the available habitat at Site 2. Once the preference criteria are developed for each day and site, they can be combined in a similar fashion, ensuring weighting factors are applied to account for different levels of effort. This process is obviously quite cumbersome and entails a great deal of work. It is also difficult, if not impossible, to determine a weighting factor to account for differences in efficiencies between techniques.

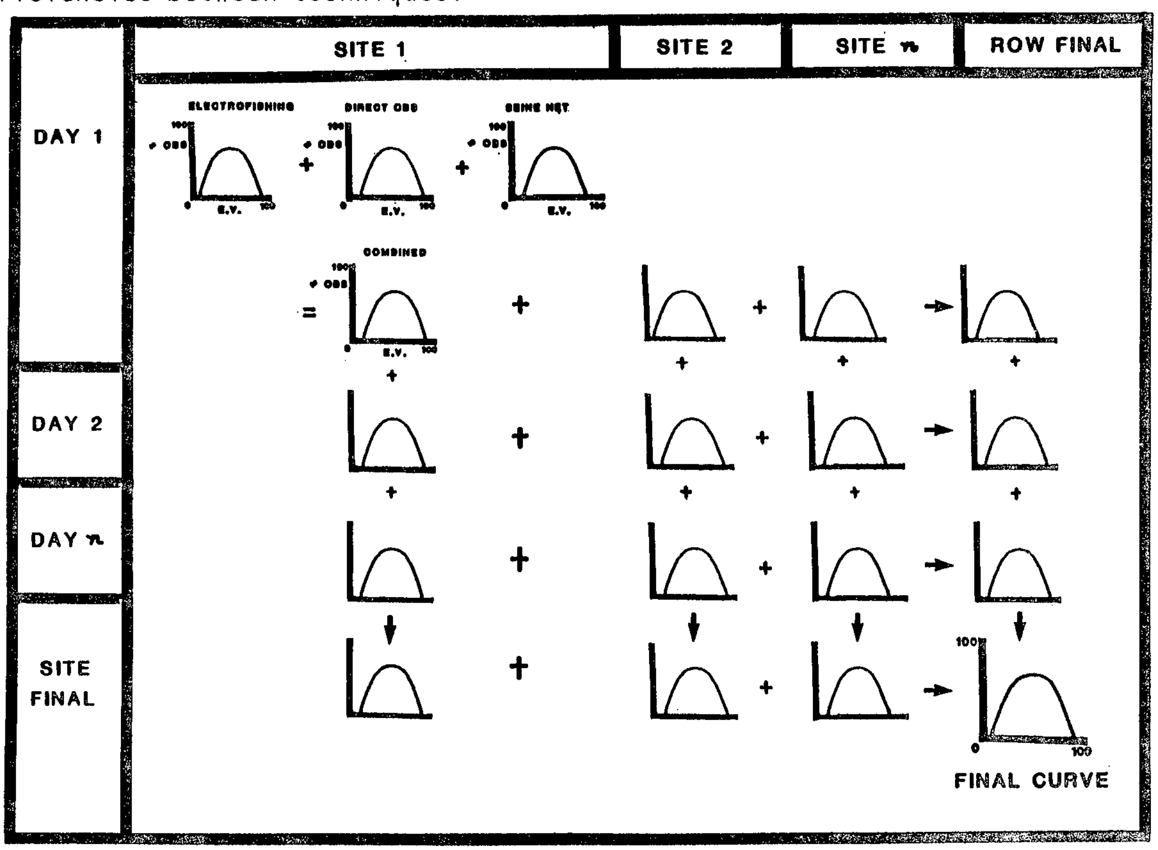

Figure 11. Theoretical worst case scenario for pooling data.

ELIMINATING DATA POOLING PROBLEMS

When developing either use or preference criteria, data pooling error can be eliminated by simple, yet effective means. Before going into the field, determine the methods of collection and analysis of data.

Pooling of data sets can be simplified by (1) using the same observation or collection technique each time for all sites, (2) using study sites of equal area, and (3) sampling each site the same number of times. This will guarantee that the frequencies of fish observation are not influenced by unequal sampling effort. An alternative to equalizing effort is to record catch per unit effort rather than raw frequencies. It is difficult, however, to define a unit of effort for many observational methods. It would probably be best to spend an equal amount of time per unit area when employing a direct observational method.

SAMPLING STRATEGIES

If an IFIM study includes the collection of site specific-microhabitat data, it will likely be desirable to develop preference criteria or Category III criteria. Some of the sampling strategies used to develop preference criteria will automatically correct for differential sample areas. Two types of sampling designs that internally correct for differential sample areas and unequal effort in each area are as follow:

(1) active capture techniques, such as electrofishing, with a standardized unit of effort used to describe utilization (P[E|F] and availability P[E] at the same time; and

(2) observational techniques, such as SCUBA, using a proportional sampling design to determine availability (Bovee 1986).

An example of the first case (Table 1) is the use of a prepositioned area shocker at randomly selected locations in three streams, outside of IFIM hydraulic sites. At each location, the environmental variables are measured whether or not fish were taken. In Stream A, 30 fish are taken with 90 set-ups; in Stream B, 40 fish are taken with 150 set-ups; and in Stream C, 10 fish are taken with 20 set-ups. Based on raw frequencies only, the environmental conditions would appear to be the best in Stream B because the most fish were caught there. On a catch per unit basis, however, Stream C is obviously better. One way to standardize the data is to use catch per unit effort instead of raw frequencies. This is unnecessary, however, because if you assume the number of samples in all streams is the same, say 150, the number of fish captured would correspondingly increase. In Stream A there would be 50 fish and in Stream C, 75 fish. The equation is already standardized because each sample represents a standard unit of effort, and therefore, each raw frequency is additive. An example is shown in Figure 12. The sure way to ensure pooling compatibility with this method, however, would be to standardize the sampling areas.

An example of the second case, using proportional sampling, is a team of divers observing fish in three stream reaches, within IFIM hydraulic sites,

Table 1. Data collected from three streams using active collection techniques.

CASE 1

	STREAM A	STREAM B	STREAM C	TOTAL
# Fish Captured	30	40	10	80
# of Set-ups	90	150	20	260
% of Total	35	58	7	100
C.P.U.E.	0.33	0.27	0.5	1.10
# Fish Captured Using Standardized P [E] (150)	50	40	75	165

where the available habitat P[E] is determined with PHABSIM habitat mapping. Reach A encompasses 25,000 m², Reach B, 15,000 m², and Reach C, 40,000 m². In this case, available habitat is determined for each increment of environmental variable on the basis of the total area in all three reaches, divided by the total surface area (Figure 13). This approach suggests that the conditions in Reach C are 2.67 times more available than those in Reach B. Again, the reason that such data can be pooled directly is that the units of availability are additive. The PHABSIM output would have to be corrected to reflect true reach length. Furthermore, all observations should be confined to actual area encompassed by the PHABSIM site, to avoid the occurrence of fish in conditions that appear, from the environmental data, to be unavailable.

SAMPLING METHODS THAT CREATE DATA POOLING BIAS

There are sampling methods that will actually create data pooling bias. One such method involves taking a standard number of random samples of the environment based on the number of fish observed, and another is systematically sampling the environment where different intervals between samples are used in different reaches.

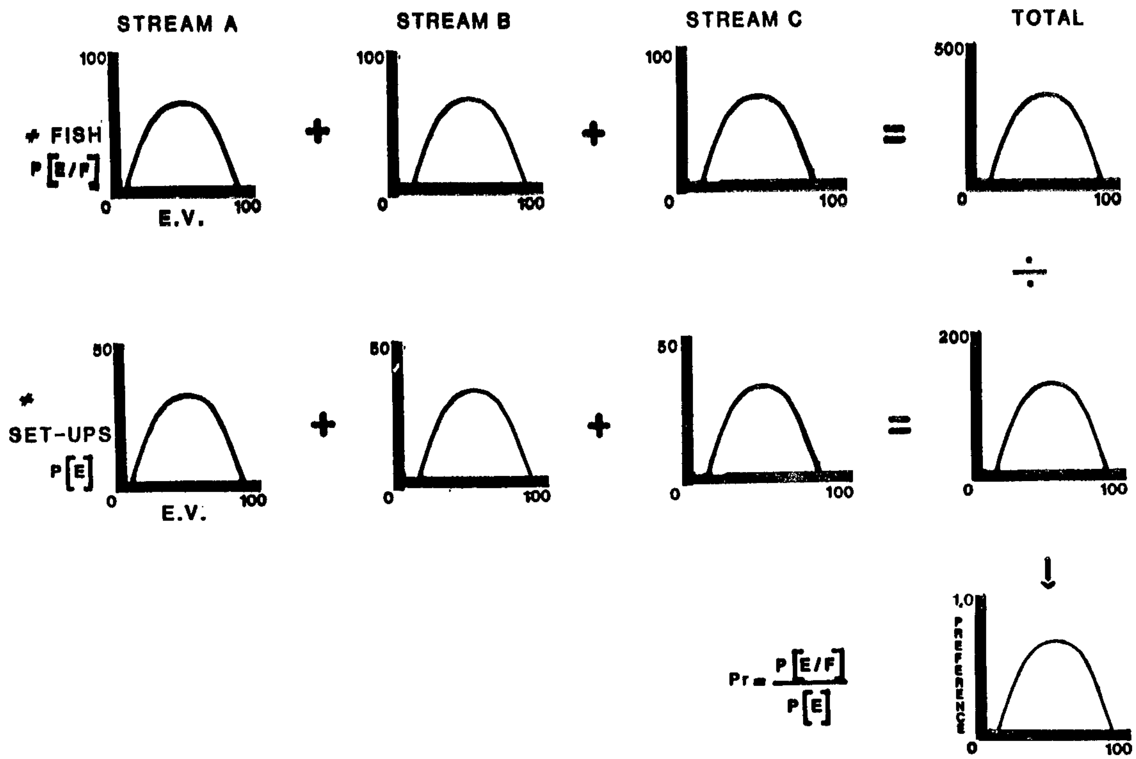

Figure 12. Directly additive data based on catch per unit effort.

In the first case, suppose that 10 random samples of the environment were taken each time a fish was observed (Figure 14). Reach A and Reach B are the same size, but 40 fish were observed in A and 20 in B. With this sampling design, 400 measurements of the environment would be taken in A and only 200 in B, implying the conditions in A are twice as available as those in B. When using random sampling, as in this case, the same number of samples should have been taken at both sites. If A is twice the area of B, then A should have twice the number of random samples.

In the second case, consider a systematic sampling design, such as a diver following a diagonal zig-zag pattern of transects across a channel (Figure 15). The diver counts fish found within a meter on either side of the line, and environmental conditions are measured at each edge and at a quarter, half, and three-quarters of the way across each transect. The problem with this is that each sample of the environment enters as a frequency, but the frequencies do not represent the same areas. The solutions to this are to either use constant spacing between measurement points, regardless of the size of stream, or select study sites that all have the same width.

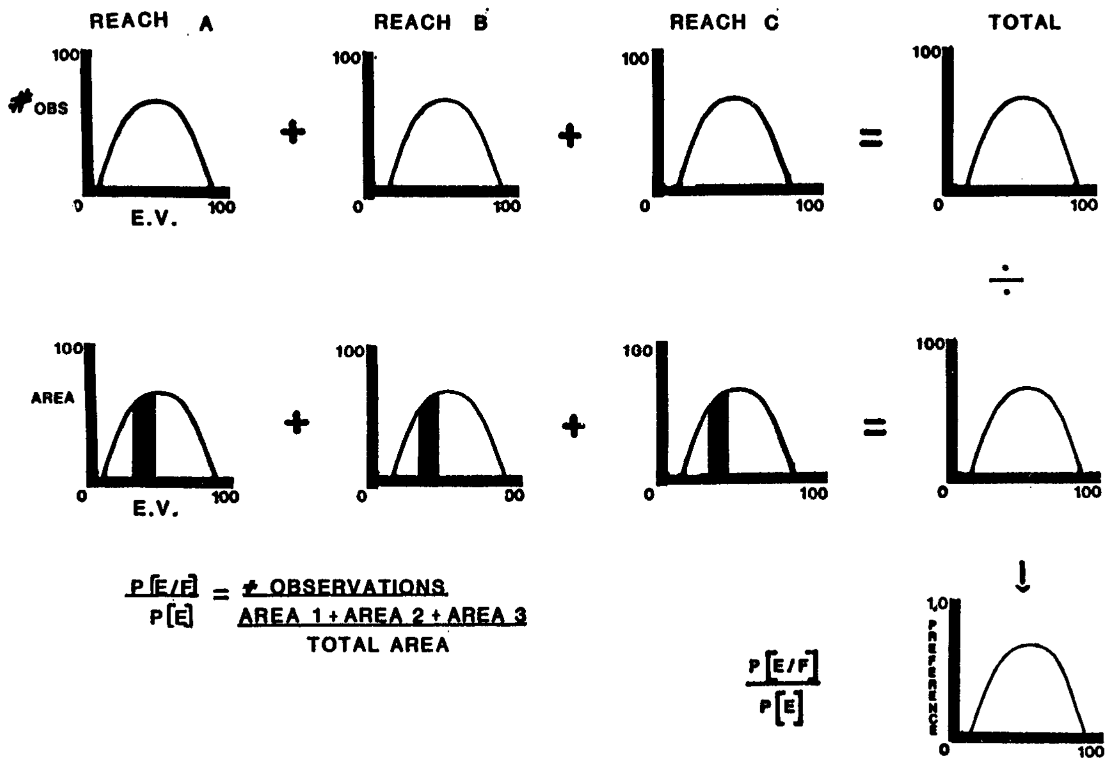

Figure 13. Directly additive data where the available habitat P[E] is the sum of the area in all reaches divided by the total surface area.

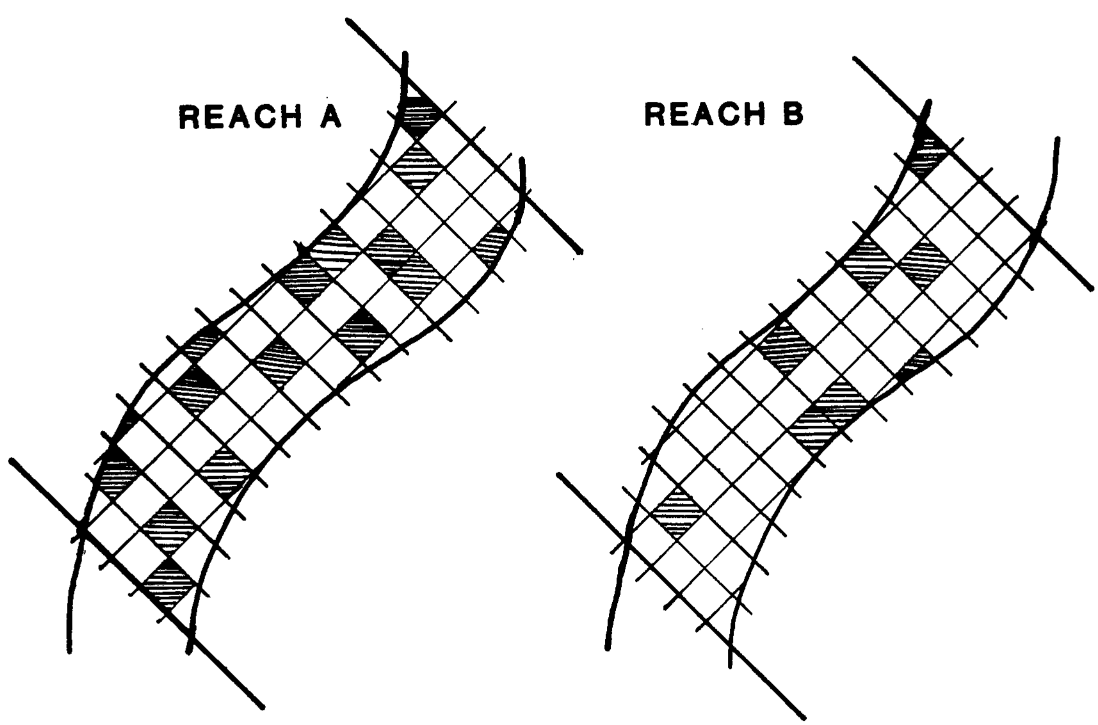

Figure 14. Improper random sampling of the environment.

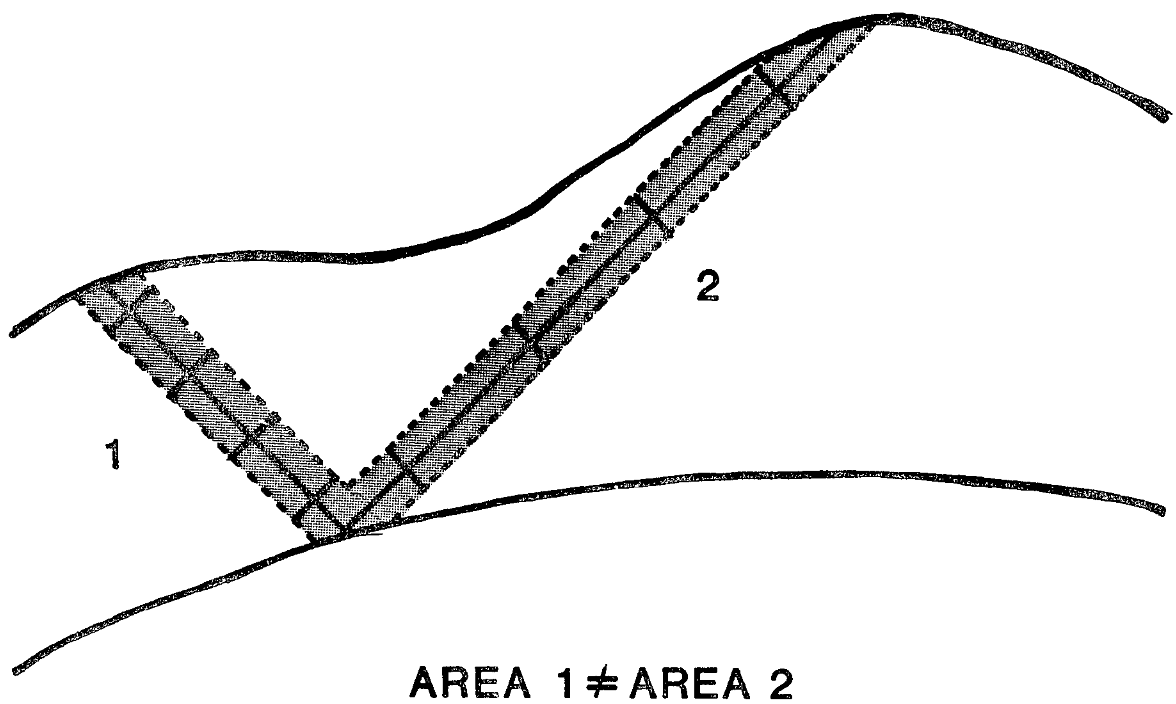

Figure 15. Systematic sampling resulting in data pooling bias.

SUMMARY

Pooling data refers to the practice of combining data sets collected from different reaches and at different times into a common data base. The crux of the data pooling dilemma is to avoid overrepresentation of data from one source. Eliminating data pooling error can be accomplished by following some very simple steps: (1) plan your study before going into the field, (2) select, if possible, one method to collect data, (3) apply the method using a standard time increment at each study site, (4) visit each site the same number of times, and (5) ensure the sample sites have the same area.

If these steps are followed, a preference curve for each site for each visit should be developed, the preference criteria added, and the final curve normalized (Figure 16). Alternatively, one use curve and one available habitat curve can be developed and the two combined to produce the Category III or preference curve. With careful planning, data pooling bias can be eliminated, and time necessary to develop microhabitat criteria can be significantly reduced.

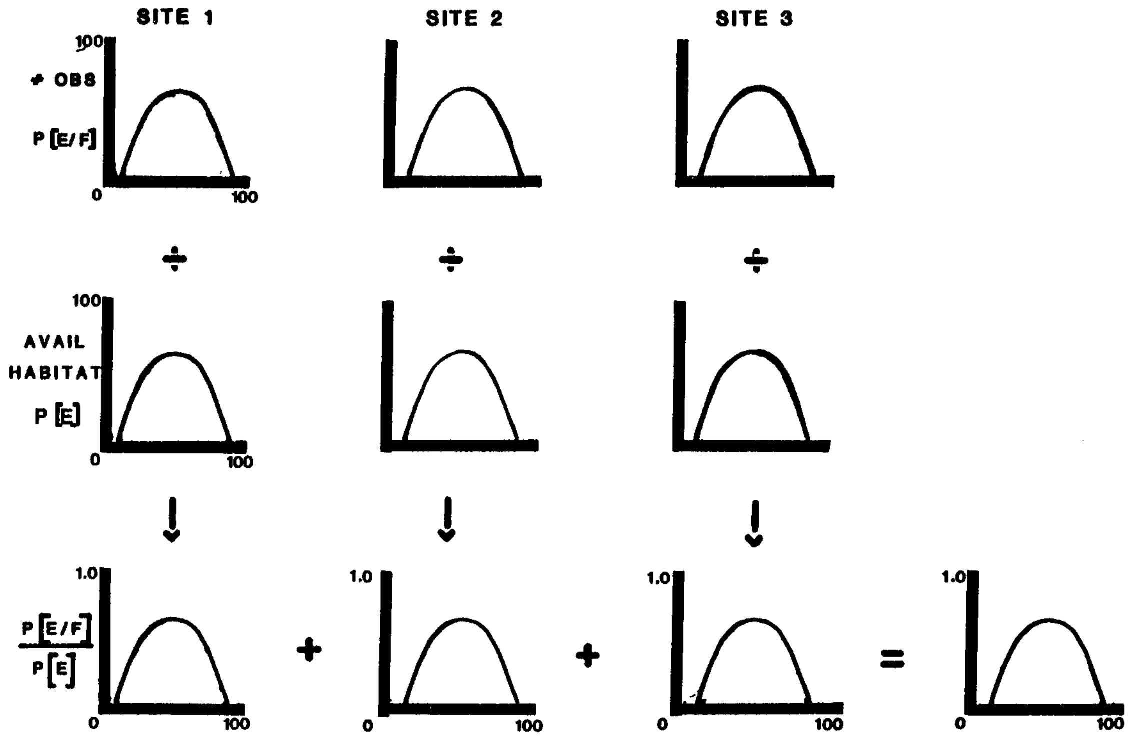

Figure 16. Determining preference criteria for each site and the final curve.

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QUESTION AND ANSWER SESSION

Alan Locke

Li: I think that from my own perspective, the issue is this: before we make these generalizations about criteria transferability, we need to look at specific cases so we can see how they vary from stream to stream and from population to population.

Locke: I would be hesitant to pool data from slow, meandering meadow streams with data from high gradient mountain streams. I think those two situations will produce very different results. I have several suggestions in terms of equalizing samples, sampling areas, or sampling effort. In terms of observation techniques, it seems that the largest problem is not maintaining the same sampling size, sampling area, or sampling effort. The real problems are created by those factors that change during the sampling period, especially water clarity. In the most turbid conditions where I have ever worked, we had about a meter and a half visibility. In eight hours of hard work we obtained twelve observations. So, how could we say we covered the same area and that the same number of observations are comparable with data coolected under better visibility conditions? Both utilization data and availability data have to take into consideration the efficiency of the observation technique. Simply using the same size study areas is no guarantee that all of the observations are going to be made with the same degree of efficiency. Unfortunately, I can't tell you how to determine efficiency under different conditions of visibility. It seems to me that you have to take enough habitat availability and utilization data so that you can feel comfortable with the results when you are finished.

Li: I can't either. In very simple channels, you can normalize your use data for each day. The problem with normalizing each day is that it results in a lot of null cell areas that make this type of analysis very susceptible to outliers. In some cases, it is necessary to compromise between normalizing the daily use data and collecting a large enough data set to develop the suitability index curves. It is going to be very difficult to equalize the sampling areas in streams with very complex channels.

Locke: After having used all these techniques, I am fortunate that all the streams I have worked in were very clear. I am now a firm believer in direct, underwater observation. It is clearly superior for taking this kind of measurement, and in any study like this that I would do in the future, I would take steps to ensure that direct underwater observations could be done.

Bovee: Alan, I think that Stacy brought up a good point. That is, we have made the assumption that when the same technique is used, then the efficiency of that technique can be ignored because it is assumed to be constant. But what if the same technique does not have the same efficiency at all times? I direct the question to the group. Is there any easy way to evaluate the efficiency on any given day?

Locke: I have an intuitive feeling about that. When I was working on the Sheep River, I used SCUBA gear to observe fish. Over a two week period, there were a couple of rainfall events up in the foothills that raised the water level and increased the turbidity. Now, the turbidity wasn't a factor in my ability to see the fish, but the behavior of the fish definitely changed. When I could see them very clearly and they could see me very clearly, they were quite content to sit and feed as long as I just maintained my position downstream from them. When the water was turbid, I could not approach them.

Parkinson: We just used direct observation techniques on brown trout in a population estimation and followed it up with electrofishing. Electrofishing didn't work as well, but this was a high gradient stream with lots of hiding places.

Barrett: In defense of electrofishing; the streams I work in are about 20 ft wide and about 2 ft deep and so turbid that SCUBA won't work. So, we use electrofishing. We have two species of Catostomus, spiked dace, Agozia, some red shiner, and all these fish are an inch or two long. You just can't get them with direct observations. I can usually tell by their behavior what species they are, but I am definitely biasing the data at that point. With our backpack electrofishing gear we just stand in the middle of a riffle and let the fish move in. We can usually tell when they are settled down and then we will shock them. We take information only from where we originally saw the fish and we don't collect any data if we think that we have chased them.

Locke: There is a fisheries biologist in our Calgary office who deals with rainbow trout fry in riffle areas. He maintains that the fish are hiding beneath the rocks and you will never see them using direct observation. Indeed, you might have to use electrofishing in that particular case.

Leonard: I would like to agree with your conclusion that there is a problem with pooling availability data. When you are pooling data from another stream, you may be adding in conditions that some of the fish could never have selected, because those conditions were not available in all the different streams. We did the same thing you talked about. We tried to develop preference curves for each of the different streams that we worked in. It was a little easier in warmwater streams where species are more abundant and higher sample sizes are easy to obtain. But it also creates problems if your curves fail to converge from these various streams. The other point that I wanted to make is that I think it is inherently wrong to use PHABSIM mapping to determine habitat availability. I say that because when transects are selected for PHABSIM, the procedure tends to be very biased. For example, transects must be placed at hydraulic controls and specific habitat types. It is not a random sampling design to get an accurate distribution of habitat availability. So just to play the devil's advocate, I am going to suggest that PHABSIM should not be used to define habitat availability.

Locke: That very point has been raised where I work. A consultant once said, "We are not going to use PHABSIM mapping when we collect our utilization criteria. We are going to take random measurments." So I asked him why we wouldn't use PHABSIM mapping. The consultant answered, "Oh, well, it is just not accurate enough for this kind of application." So I responded, "Well, if

it will work on the hydraulics, why won't it work for this?" My question is, "Should we use transect sampling, pick random points, or what is the sampling strategy?" Bovee (1986) has two suggestions, one of which is to use PHABSIM mapping. Perhaps it is time to come up with another one.

Li: One thing that makes PHABSIM mapping difficult is that it depends on how the channel morphology is described. For example, if transects are placed at fixed intervals along the stream, this is essentially a random sampling design, and the number of sample points depend on the width of the stream. If transects are placed at major habitat breaks, and verticals placed at every substrate change, then this is something else. The interesting point is that either of these two techniques could be used to generate PHABSIM output and they may or may not be the same. The main reservation that I have to using PHABSIM mapping to determine availability is this potential for lack of reproducibility.

Leonard: Let me clarify one thing I said. I said it depends on how you use PHABSIM. If you are using a representative reach concept and using a strict habitat mapping approach, ignoring hydraulic controls concentrating on habitat, that is one thing. If you are using a program like WSP (Water Surface Profile, a hydraulic simulation program--eds.), transects must be placed at hydraulic controls. That is a very different situation.

Hilgert: I have been concerned about this discussion. What is the goal of hydraulic modeling with PHABSIM? I thought the objective of developing a PHABSIM study site was to describe the habitat in the river in the proportion of its occurrence. I assume this is the same objective of using random sampling. Theoretically, the results should be the same with PHABSIM transects or random sampling. Everybody seems to be relying upon random group measurements to determine habitat availability. Why hasn't this been promoted as "the" method to develop availability instead of using transects? I, for one, think that using transects is much better than random group methods. I try to look at as much of the entire stream as possible, then set up transects to define the main habitat types that occur. Important habitats might be minor in their areal extent, but critical to the species, and must be included. If that has been done properly, then you can assume that the habitat map represents the habitat availability as it occurs in that stream.

Li: I have no problem with that if the representative transect approach is used, but not the representative site approach.

Aceituno: We used both the habitat mapping approach and random sampling and this will be the last talk tomorrow afternoon.

Locke: My final comment on this whole subject relates to the cost of the study. I would rather work within an IFIM site that was selected to be representative of the reach, if for no other reason than simple economics.

Smith: You developed preference curves for each site individually and then averaged the preference curves to come up with the final curves. Did you also pool all of the data and develop a final preference curve that way? If so, did you see any differences in the final preference curve?

Locke: Yes, I did, although I didn't use real data. I used general data points and I put in values for all these curves. I did it both ways and I got the same result, but I don't believe it. I think there should be a difference, but there is no difference. Bovee (1986) suggests that they should be equal and you can add raw frequencies for both utilization and availability. I don't know about that. It would seem that the fish utilizations in one stream would not have the same conditions available as the fish in another stream. Intuitively, pooling all the data first seems wrong, but it worked.

Li: One of the problems that I have encountered is that when I sample several streams on several different days, I may find different numbers of fish in each stream on each day that I visit. In some cases, that results in building a preference curve with very few data points. You have really meaningless data for curve construction if you only have one or ten observations in one stream and 75 or 100 in another.

Locke: That is a very valid point. The work that I did on the Sheep River used the same site, but I had replicate utilization data. So I had several utilization data sets, but only one availability data set. I was very fortunate that the discharge didn't change. So when I added up the raw frequencies, I had enough data to satisfy sample size requirements and I could assume that I had the same availability for the entire sampling period.

Corning: It appears to me that that is probably a factor of magnitude. The smaller your sample, the more important it would be to develop separate preference functions and compare them. The larger the sample, the less need to do that. In other words, once your sample size get so large, it really doesn't matter how you do it.

Locke: So, in other words, if the study design follows the suggestions in Information Paper 21 in terms of area, then you can pool all the data.

Hanson: Did you actually develop individual preference curves using real data from site one, site two, site three, etc.?

Locke: No, this is just an example. I just put in a generalized curve for each of these. I made each utilization and availability function different, but the final preference function ended up being the same.

Hanson: How are you using this approach? If you were using real data you would develop three independent preference curves. I can understand why you would get different utilization curves, but if you find different preference curves, you need to assess the reason for the difference. Are there really different preferences, or do the differences reflect inadequate sample size for each preference curve?

Locke: The only reason that I developed the individual preference functions was that I just felt uncomfortable about the available habitat in one stream having anything to do with utilization in a different stream, which is implied when all the data are pooled. So to overcome that, why not just develop individual preference curves? These turn out to be very similar. We may be just changing the tails a little bit.

Leonard: If anyone feels compelled to develop individual preference functions instead of aggregating all the data, I think Dave (Hanson) is right. I think that you should try to determine the reasons for those differences. This is the perfect opportunity to inject some professional judgment when developing the final preference function. Maybe you can identify some reasons related to sampling or availability why these preference curves are different. I think that is a good place for professional judgement.

Hanson: One of the problems with using availability data is that you can get a totally different preference curve between sites or a total lack of habitat at some of the sites.

Locke: My comment is that when you pick a site to measure available habitat, it should be the same place where you measure utilization. If the site has a run, riffle, pool, or whatever, the availability distribution shouldn't show that it has none. In other words, if that is the characteristic of the stream, you should ensure that it has been included in the sampling so you shouldn't have that problem.

Jean Caldwell: I agree with you, but I disagree. I think it is too easy to say that you shouldn't have that problem, even though you know that you will.

Peters: I would just like to speak up for the region of the country that lies between the clear water on the West Coast and the clear water on the East Coast. In the turbid water of the midwest, we have yet to see a fish without having collected them by some sampling technique. So we are inclined to sample and obtain our data on fish distribution and utilization of different habitats by various sampling techniques. One sampling technique will not work in all of the different kinds of habitats that we have to deal with. Consequently, we have to pool data.

Locke: Well, I don't know what it is like working in those rivers, but the one thing that comes to mind is that we spend a great deal of time and money to develop criteria. I think we should ensure that the product we get is something we can have some faith in. I am not from your area, but I know that even under excellent conditions, criteria can be very costly and there are many pitfalls in their development.

Peters: We still have the responsibility for making recommendations on stream flow and this may be one of the best techniques to use. It is going to be expensive.

Smith: Did you notice any difference in your ability to approach the fish in turbid water and in clear water conditions?

Locke: Oh, very noticeable. Under clear conditions, we can approach the fish very closely from behind, but never from upstream. I would almost have to grab out before they would start off. In fact, when I put a marker down and came back to take the measurments, the fish were in the exact location where I had spotted them in the first place. Under turbid conditions, they were flightly and wouldn't let me approach. I could just barely see flashes from the sides of their bodies.

Campbell: Our experience has been that when the fish are holding territories, they can be approached, but when they are schooling in very low velocity water, they keep moving on ahead of you. It is very difficult at that point to get as high quality observations as in clear water with fish holding territories.

Aceituno: What is the group's opinion on pooling data in various situations? Has anybody had time to compare utilization curves for the same species separately and using pooled data to see if they are similar or not?

Hanson: An issue that is going to be discussed in the future in this workshop is what to do when availability changes, but the fish do not move from where they were found previously. The issue there is when should you use utilization and when should you use preference? If the availabilities change, you may have an apparent shift in preference. Then, we will have to correct one or the other or somehow figure out what kind of statistics to perform on the results.

Question from the floor: That is what I was wondering. Do you actually correct the utilization function or do you use separate utilization functions for separate streams?

Hanson: If you have the same fish populations, with the same species associations and so forth, in different streams and you assess habitat utilization, you should get the same preference curves. In other words, if the fish like water two feet deep in one stream, they should like water two feet deep in another stream. If you don't get that, then you need to ask yourself some questions about why you didn't. That is one of the reasons that I am not too wild about averaging the preference functions.

Lifton: Another thing to be aware of is that the amount of data you have is going to affect the tails of the distribution. Very often most of the data will be clustered near the central part of the distribution. Channel structure appears to have a considerable amount of influence on the habitat availability distribution. Habitat availability starts having an effect on the distribution in the region of marginal habitat. I have looked at two streams, both at different flows, and I came up with the same utilization curves. I believe the reasons for this result are because of a good sample size and because the local velocity distribution remains the same due to the channel shape. However, we do get an apparent peak at the high end of the velocity preference curve due to low fish observations and lower availabilities. One way to get around this is to confine your sampling to velocity strata. That way, the availabilities remain neutral when you compare various flows.

Campbell: One of the complicating factors when the discharge changes throughout the season is that there will be a shift in the availability along the discharge curve. One of the assumptions is that the fish are selecting a particular velocity. If the velocity distribution moves with the shift in discharge, then the fish should move with it, but sometimes they don't.

Lifton: On the other hand, local conditions may remain very stable over a wide range of flows. For example, if a fish is hiding behind a rock, the local conditions at that location are pretty stable over a wide range.

THE SAFARI FACTOR: THE FIELD BIOLOGIST'S GUIDE TO CROWD CONTROL

by

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Weathermen have the Wind Chill Factor, fisheries biologists the K Factor, and I would like to introduce a new term for field biologists--the Safari Factor. The principle behind the Safari Factor, briefly stated, is as follows: Any task has an optimum number of workers; the more this optimum number is exceeded, the more inefficient the work becomes. For example, to seine fish the optimum number of people is three, two to seine and one to carry the clipboard and the measuring board and to help measure fish. Adding additional workers does not increase efficiency and will eventually decrease it. This same principle also applies to vehicles and the division of key equipment or personnel into separate groups.

I coined this term several years ago when collecting trout in Arizona. This was a two-person, one-vehicle task. When I counted up the people, vehicles, and miscellaneous from "involved agencies," however, I found nine people (including one spouse), five vehicles, and a dog. The whole entourage reminded me of a scene from "Rama of the Jungle," hence the name "Safari Factor."

In instream flow studies, it is almost guaranteed that the Safari Factor will rear its ugly head. This is because of the team concept, a pillar of instream flow studies. I will give a hypothetical, but not too far-fetched example, to demonstrate this point. A project is proposed that will divert streamflow to several cities along its course. The instream flow team will include key players from the following agencies: (1) the Fish and Wildlife Service, which will be the lead agency, (2) the action agency (U.S. Army Corps of Engineers), (3) the land management agencies (U.S. Forest Service and Bureau of Land Management), and (4) the State game and fish department. Of course, there will be more team members if the project involves several States, more land management agencies, or local and regional offices of the same agency. In addition to the team members, there will undoubtedly be extra "help" from supervisors who want to "get the big picture" or "see what's going on in the field." Sound familiar yet?

By now we have a large enough field crew to seriously increase our Safari Factor, so we will add an additional insult--vehicles. Increasing the number of vehicles also increases the Safari Factor. It would be possible to get our

oversized field crew into two vehicles, but this never happens. Instead, we will probably meet at a check point (or several check points) and proceed to the work site. The greater the number of vehicles in the convoy the greater the chances of delay. Invariably, someone will be late due to last minute work at the office, car trouble, getting lost, oversleeping, . . . ad infinitum.

Now that the field crew and number of vehicles are bloated enough to insure a high Safari Factor, we can deliver the coup de grace. This can be accomplished by having key people or equipment in different vehicles. For example, having the survey equipment, flowmeter, and measuring tapes in three different vehicles can create peptic-ulcer-aggravating delays.

These three factors, number of people, number of vehicles, and division of key equipment or personnel, can work either alone or synergistically to create the Safari Factor. Figure 1 displays Safari Factor estimates for various situations. These estimates are based on empirical data gathered over many years of field work. Figure 1 may be used to estimate the Safari Factor of planned field work so the appropriate amount of time may be scheduled.

Like many basic principles, the Safari Factor is intuitively obvious when it is pointed out, but can cause extreme frustration and much gnashing of teeth for those who are naive to its existence. Now that I have made such a strong case in warning against the Safari Factor, I must back down a little. I am like many in that when I have a job to do I want to get it done. Give me an optimum (usually small) field crew and, using guerrilla tactics and eating granola bars, we can crank out the work. While delays and inefficiency caused by a high Safari Factor are truly frustrating, they are also inherent in most interagency work. Unfortunately, a high Safari Factor is the price we must pay to keep everyone abreast of the project and to insure proper coordination. This coordination, in the final analysis, is vital to the success of the project. In short, we have to accept a certain Safari Factor as a necessary evil.

Although we may have to accept the Safari Factor as a necessary evil, the following suggestions will aid in keeping it to a minimum:

1. Have a "work unit" in one vehicle, i.e., optimum field crew, vital equipment, and key personnel.

2. Divide large groups into smaller, more efficient crews.

3. Have separate "show and tell" trips for the bureaucrats and supervisors, i.e., do not mix field work with informational trips.

The next time you are planning field work and someone says, "I'll meet you at the stream and bring some help. You get some people from your office and the seines, Sally can get some of her people and bring the electrofisher, and we'll see if the folks from State can come and bring their flowmeter." Beware!

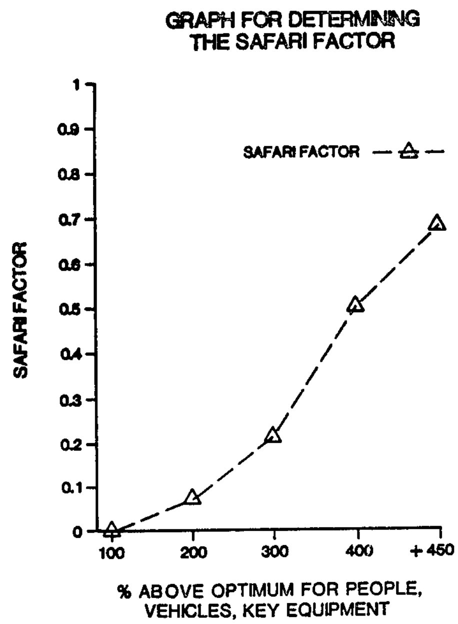

Figure 1. Graph to determine Safari Factor based on the percent above optimum of the number of people, vehicles, and division of key equipment or personnel.

The Safari Factor is computed from the above graph by determining the percent that the optimum number for a task is exceeded in three different areas: (1) number of workers, (2) number of vehicles, and (3) division of key equipment or personnel. These three values are summed, then multiplied by the number of work days anticipated. This number is then added to the anticipated work days to yield actual work days.

Example. You plan to gather data to build species habitat perference curves. The optimum for this work is three people and one vehicle. You anticipate the work taking three days. On the scheduled work day you find you have six workers in three vehicles with vital equipment divided between two vehicles. The Safari Factor taken from the above graph is as follows.

CATEGORY	PERCENT OF OPTIMUM		SAFARI FACTOR
1. Number of workers	200		.07
2. Number of vehicles	300		.21
3. Division of key personnel or equipment	200		.07
		SUM	.35

Your Safari Factor is .35

Anticipated work days x Safari Factor = Additional work days

3 x .35 = 1.05

Additional work days + Anticipated work days = Actual work days

1.05 + 3 = 4.05

AN EVALUATION OF SAMPLING METHODS AND STUDY DESIGNS FOR QUANTIFYING HABITAT UTILIZATION BY STREAM FISH

by

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ABSTRACT

To identify the relative influence of fright bias and investigator bias on habitat utilization data, a field study was conducted to obtain three data sets differing in sampling technique and sampling design. Physical habitat measurements were made for 1,175 blacknose dace (*Rhinichthys atratulus*) captured in a single 160-m stream section using: (1) backpack electrofishing without an a priori sampling design, (2) backpack electrofishing with an a priori sampling design, and (3) a 2.8-m^2 prepositioned area electrofishing device with an a priori sampling design. Differences among the data sets could be attributed to sampling biases, since all data sets were obtained from the same sample population. The differences among the three data sets indicate that both fright bias and investigator bias affected the habitat utilization data. These biases were not only statistically significant but also altered the frequency distributions enough to affect habitat suitability curves. Overall, the use of an a priori sampling design appears to be more critical than the selection of particular electrofishing equipment for studies involving small streams and small fish.

INTRODUCTION

An electrofishing device and sampling procedure were recently introduced for obtaining data on habitat utilization by stream fish. The equipment and

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[1]Cooperators: U.S. Fish and Wildlife Service, Game and Fish Division of the Alabama Department of Conservation, Wildlife Management Institute, and Auburn University (Agriculture Experiment Station, Department of Fisheries and Allied Aquaculture, Department of Zoology and Wildlife Science.)

procedure were initially described by Bain and Finn (1982), subsequently evaluated for quantifying habitat use by stream fish (Bain et al. 1985a), and named the prepositioned area shocker by Bovee (1986). There were two primary reasons for developing the prepositioned area shocker and sampling procedure: minimize "investigator effect" and "investigator bias."

Investigator effect is a change in an animal's behavior due to the presence of an investigator or stimuli from the investigator (Lehner 1979). Fishery biologists attempting to record undisturbed fish locations refer to this phenomenon as "fright bias" (Bovee 1982). Fright bias is commonly noted in clear waters when sampling is directed at highly mobile fishes (e.g., adult smallmouth bass, Micropterus dolomieui). Fish flee from samplers and tend to be caught or observed after being driven into cover or areas where further movement is restricted. Fright bias has been noted or minimized in some studies (e.g., Larimore 1961, 1985; Horton and Cochnauer 1978; Bain et al. 1982; Shirvell and Dungey 1983; Loar et al. 1985; Hearn and Kynard 1986) and is probably far more common than indicated in published research. The prepositioned area electrofishing device minimizes fright bias by being positioned in the sample area and left undisturbed until activated from a remote location.

Investigator bias refers to the effect of investigator decisions made at the time samples or data are being obtained. In the classic sampling methods paper by Altmann (1974), investigator bias was identified as an unintentional and pervasive factor significantly influencing the accuracy of field data collected without an a priori sampling design. For example, Larimore (1985) recently stated that biologists tend to sample habitat where they expect to find their quarry and ignore "poor" habitat. This tendency, a form of investigator bias, may occur unconsciously any time investigators are making even minor decisions on habitat to sample while sampling. Even though investigator bias is covered in introductory research methods texts (e.g., Lehner 1979) and methodological manuals (e.g., Bovee 1986), it has not yet become widely addressed in microhabitat-related field studies. The sampling procedure used with the prepositioned area shocker employs an a priori, transect-based sampling design that minimizes potential investigator bias.

In 1981, I collected habitat utilization data on smallmouth bass in a Massachusetts river using two approaches: visual observation without an a priori sampling design (Bain and Ross 1982) and prepositioned area electrofishing with an a priori sampling design (Bain and Finn 1982). The habitat utilization curves developed from each data set were very different. Both fright bias and investigator bias were suspected to have had an important influence on the data sets. To identify the relative influence of fright bias and investigator bias on habitat utilization data, a study was conducted on habitat use by blacknose dace, with field procedures differing in sampling technique (backpack electrofishing vs. prepositioned area electrofishing) and sampling design (none vs. predetermined systematic). In this paper, a comparison is made among three different data sets collected on an easily captured fish in a single stream reach. The results demonstrate the importance of careful sampling and an a priori sampling design.

METHODS

During August and September 1982, sampling was conducted on a single 160-m reach of the South River, Conway, Massachusetts. The South River, at the study site, is a small stream (mean annual discharge = 1.492 m^3/s) with primarily sand to boulder substrate, little instream debris providing cover, and moderately conductive water (160 micromhos/cm during sampling). Discharge during sampling was nearly constant (0.0844 ± 0.0088 m^3/s recorded by a U.S. Geological Survey stream gage in the study reach) and typical of late summer base flow.

Blacknose dace was selected as a study species because it was very abundant in the South River and easy to capture with electrofishing equipment. This species has specific physical microhabitat requirements (reviewed in Gibbons and Gee 1972; Trial et al. 1983) that would be reflected in habitat utilization distributions. Finally, blacknose dace are small bottom-dwelling fish that, in swift streams with coarse substrate, would not be expected to be easily displaced significant distances by cautious investigators. To maintain a consistent minimum size for sampled fish, blacknose dace less than 20-mm total length were excluded from the data set.

Three different data sets were collected by varying sampling technique and sampling design: (1) backpack electofishing without a priori sampling design, (2) backpack electrofishing on 21 evenly spaced transects, and (3) prepositioned area electrofishing on 21 evenly spaced transects. Backpack shockers (Smith-Root Inc., Type VII) were set at 500 volts direct current to obtain an output of approximately 0.25 amperes. The prepositioned area shocker was 5.7 m^2 (3.8 x 1.5 m) in total area, but was divided by a white cord into two separate 2.85 m^2 (1.9 x 1.5 m) sample areas. A 230 volt, 2.2 ampere, alternating current generator was used to power the area shocker. Fish sampling in this study required a crew of two (one netter and one backpack shocker or generator operator), since the stream and samples were relatively small and convenient for field work.

The first data set, obtained by backpack electofishing without a sampling design, was collected by two investigators experienced in habitat utilization studies. The 160-m study reach was sampled in a thorough and representative manner by moving upstream and periodically placing the electrodes and then activating the power supply. When blacknose dace were immobilized, they were netted and the spot was marked by a blaze orange marker. The captured fish were counted, measured, and held for later release in the area. When sampling was completed for the day, physical habitat characteristics were recorded for the capture locations. Depth and velocity were recorded with a wading rod equipped with a pygmy-type vertical axis current meter set six-tenths of the depth from the water surface. Substrate coarseness was quantified using a 1-m lead-core rope with ten 10-cm sections, according to the procedure of Bain et al. (1985b). Substrate categories as coded in this study were: 2 = silt (≤0.08 mm), 3 = sand (>0.08 - 2 mm), 4 = gravel (>2 - 16 mm), 5 = pebbles (>16 - 64 mm), 6 = cobble (>64 - 256 mm), 7 = boulders (>256 mm).

The second data set was obtained by backpack electrofishing on 21 permanent transects positioned perpendicular to the thalweg and 8 m apart at midstream. The fish and habitat sampling procedure was the same as that used to obtain data set one except that sampling was restricted to the transects. The backpack shocker samples were located on the transects by placing electrodes slightly on either side of the transect line. Transects were sampled in alternating directions (left bank to right, then right to left) and each transect was covered twice (on different days).

The third data set was obtained by sampling with prepositioned area shockers on the same 21 transects used for data set two. Six 2.85-m^2 samples were collected on each transect by setting three 5.7-m^2 area shockers (each shocker divided into two sampling areas) on each transect, one along each stream margin and one in midstream. Bain et al. (1985a) provide details of the sampling procedure outlined here. All fish were recorded in the 126 different prepositioned area shocker samples (21 transects with 3 two-sample area shocker sets). One area shocker was set at one of three transect sampling locations during each day of field work (left bank, middle, right bank on successive transects). Physical habitat was quantified as described above for data set one.

All data sets were obtained from the same sample population so any differences among them could be attributed to sampling biases. The data sets were compared in two ways. First, relative frequency histograms were constructed for blacknose dace distribution on each of the three physical habitat variables (water depth, current velocity, mean substrate coarseness). Relative frequency histograms are generally used for developing habitat suitability curves, so comparisons based on them reveal biases that could affect suitability criteria. I emphasize the range, mode, and median for comparisons among the three data sets, since there are several approaches to developing habitat suitability curves (reviewed in Bovee 1986), and some investigators directly use histograms for habitat suitability criteria. The second comparison among data sets was a statistical test of the hypothesis that the samples came from the same population. This statistical comparison was done using Kruskal-Wallis one-way layout tests. If the data sets significantly differed, multiple comparisons were made using Kruskal-Wallis mean ranks to identify which data sets were different.

RESULTS

Each data set contained physical microhabitat values for large numbers of blacknose dace and required very different amounts of fish sampling effort (Table 1). The two backpack shocking data sets were similar in the length of time used to locate fish for microhabitat characterization. However, even though data set two is large, it does have considerably less fish locations than data set one. Data set three was the largest obtained, but required a large amount of field effort compared to the other two data sets. Although not presented here, data set three contained habitat utilization data for six additional species of fish and more than 700 total fish.

Table 1. Sampling procedure, number of blacknose dace recorded, and sampling time requirements for each of the three data sets.

Data set	Sampling technique	Sampling design	Blacknose dace recorded	Sampling time Hours	Sampling time Minutes	Days in the field
1	Backpack shocker	None	442	3	40	4
2	Backpack shocker	Transects	293	3	20	2
3	Area shocker	Transects	499	16	40	3

The distribution of blacknose dace with regard to current velocity appears different among the three data sets (Figure 1), and the data sets are statistically different ($P < 0.001$). The two transect sampling data sets appear similar with regard to mode and median velocity (Figure 2) and are not significantly different ($P > 0.05$). However, data set one includes maximum velocities and a median that exceeds those of the other data sets, and modal velocities do not include very low velocity or zero velocity water.

The results for depth are similar to those obtained for current velocity. The relative frequency distributions for the three data sets appear different (Figure 3), and the Kruskal-Wallis test indicates the differences are significant ($P < 0.001$). The two transect sampling data sets are not statistically different ($P > 0.05$). While the range of depths used by blacknose dace is similar among all three data sets, the mode and median of data set one is greater than the other data sets (Figure 2).

For substrate coarseness, the three data sets are significantly different ($P < 0.001$); however, the two backpack electrofishing data sets are not different ($P > 0.05$). The relative frequency distributions of the three data sets vary somewhat, with the area shocker data set the most distinct (Figure 4). The area shocker is the only distribution with a clear mode. In contrast, the backpack electrofishing data sets have a relatively flat distribution through the intermediate substrate categories and slightly higher medians.

DISCUSSION

The differences among the three data sets indicate that both fright bias and investigator bias affected the habitat utilization data. These biases were not only statistically significant, but altered the frequency distributions enough to affect habitat suitability curves. Therefore, fright

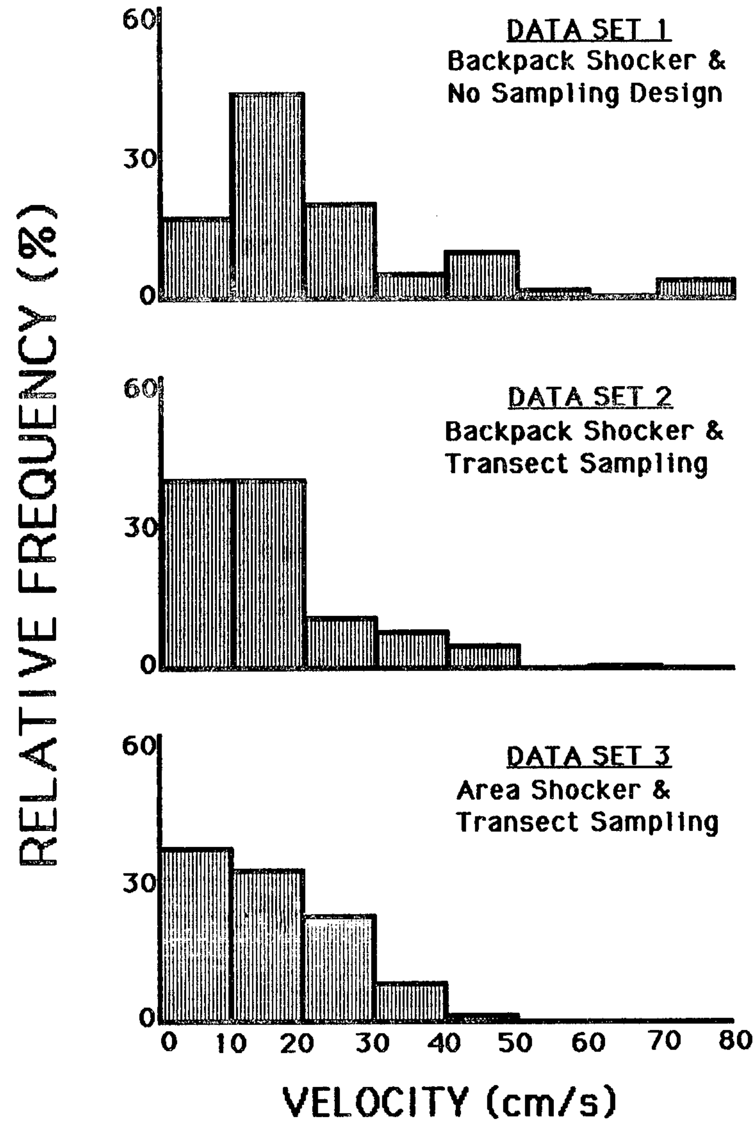

Figure 1. Relative frequency distributions for velocity use by blacknose dace obtained by the three sampling procedures.

bias and investigator bias could influence fish habitat criteria, minimum flow recommendations, habitat quality assessments, and other uses of habitat utilization data. The significance of fright bias and investigator bias in studies involving different aquatic systems and fish species cannot be determined from this study; however, this study has demonstrated that these biases can be important. Fright bias and investigator bias are likely to be influential in other studies, since the South River was small and easy to sample, and blacknose dace are not especially sensitive to sampling disturbance.

The comparisons among data sets indicate that sampling design was more important in this study than sampling technique. For the velocity and depth variables, the data sets differed on the basis of sampling design. There were no significant differences in velocity and depth distributions between the

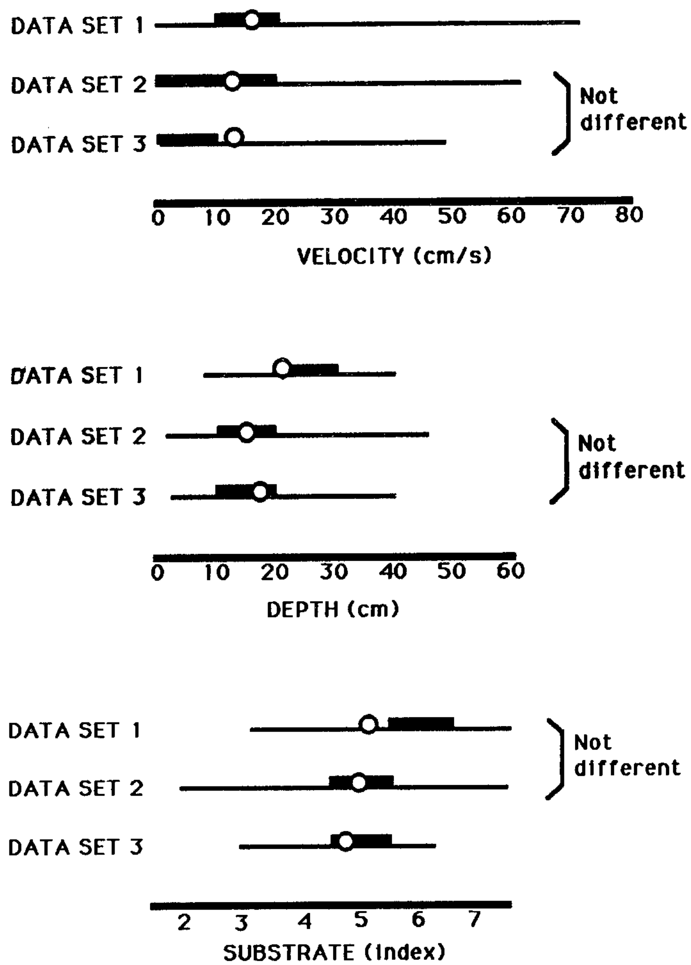

Figure 2. Range (light line), mode (heavy line), and median (circle) of habitat use distributions. Data sets not found to be significantly different are indicated by the brackets.

data sets employing an a priori study design (data sets two and three), even though they differed in sampling technique (backpack shocker, area shocker). Consequently, the use of an a priori sampling design was important for accurate data on depth and velocity utilization. Fright bias did not appear to be a significant factor influencing the velocity and depth distributions, so the type of sampling technique appeared inconsequential for these variables. However, for substrate utilization, the data sets differed on the basis of sampling technique. There were no significant differences in substrate distribution between the backpack shocker data sets even though they differed in sampling design. Therefore, the type of sampling techniques appeared to be important with regard to only one of the three habitat variables.

The data set that best reflects the true microhabitat utilization of blacknose dace in the South River cannot be conclusively determined from the information collected in this study. Data set three can be assumed to be the

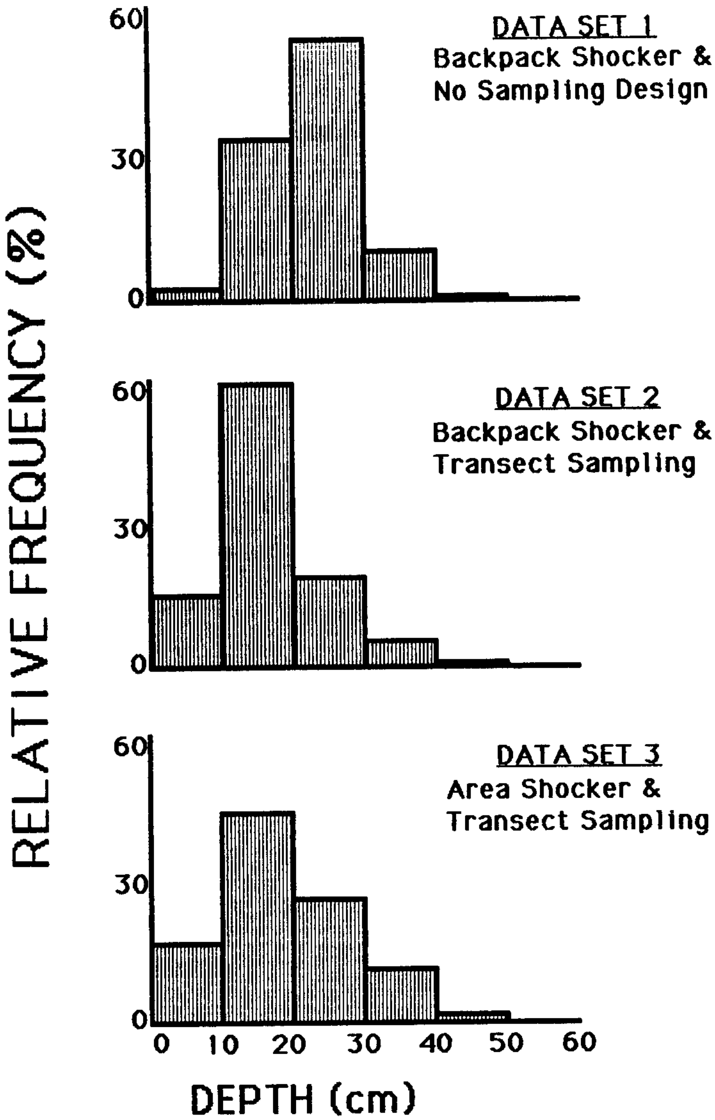

Figure 3. Relative frequency distributions for depth use by blacknose dace obtained by the three sampling procedures.

least biased of the three data sets, since specific measures were taken to minimize fright bias and investigator bias. Under this assumption, the differences among data sets can be used to explain how each type of bias may have had an effect. Without an a priori sampling design, the field investigators may have unknowingly undersampled shallow and slow shoreline areas with fine substrate. Such a bias would shift the habitat utilization distributions toward greater velocities, greater depths, and more coarse substrate. When constrained to the transects, the investigators obtained depth and velocity data that were not different among sampling techniques. Use of the prepositioned area shocker resulted in greater numbers of blacknose dace found in association with fine substrate, which appears to have been most affected by investigators in the stream. When disturbed, the fish may have moved to more coarse substrate areas, since boulders and cobble provided the

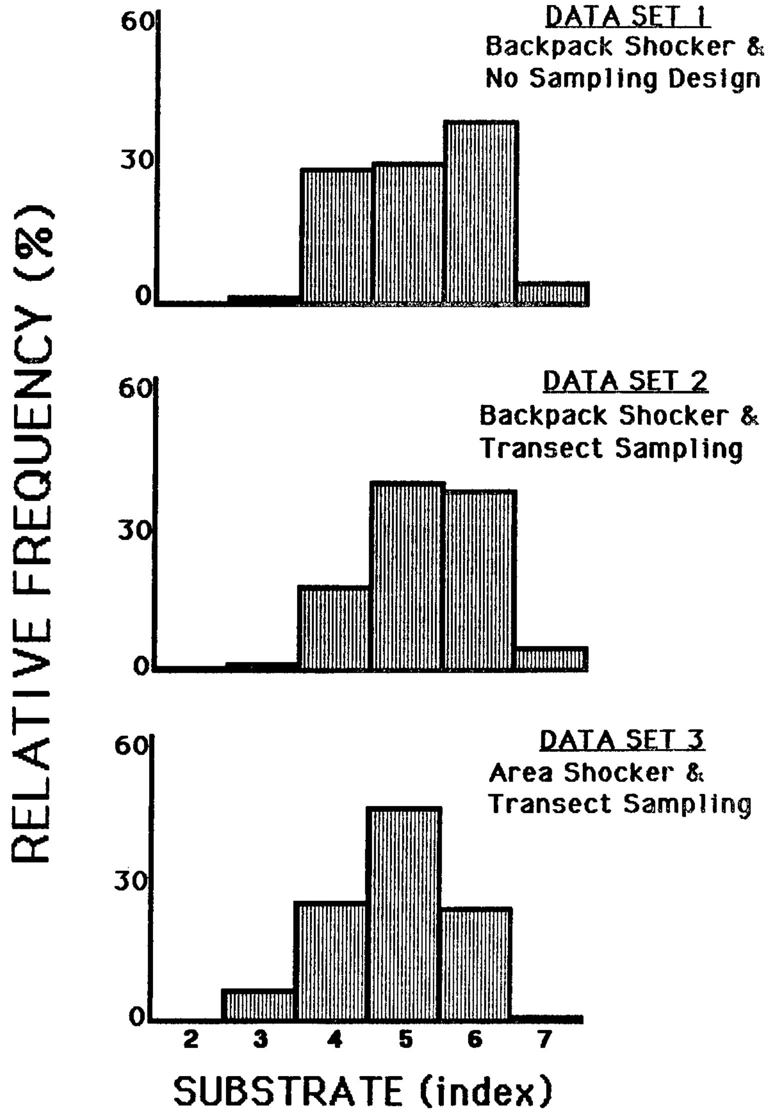

Figure 4. Relative frequency distributions for substrate use by blacknose dace obtained by the three sampling procedures.

only instream cover. In addition, the utilized range of all the variables tended to be small when sampling was done with the prepositioned area shocker. The larger range of backpack electrofishing data indicates that at least a few fish may have been displaced beyond the usual microhabitat conditions.

While fright bias is widely recognized as a potential problem, investigator bias seems to be relatively ignored. Bovee (1986) states that some of the largest sources of bias in habitat utilization data can be traced to poor, or no, sampling design. Typically, investigators are primarily concerned with obtaining "enough" data. Without any particular sampling plan, the investigators get to the study site and collect as much data as possible in the most expeditious manner. Altmann (1974) calls this approach "ad libitum" sampling, since investigators commence data collection without

preparation and make sampling decisions as needed. The primary problems with this approach are a tendency to concentrate on areas easiest to sample, areas perceived as being the correct habitat, and individuals easily observed or captured due to their activity or size.

Presumably, ad libitum sampling is the approach employed in most studies in which no mention is made of sampling design. Unfortunately, this includes some of the most significant fish habitat research conducted to date (e.g., Orth and Maughan 1981, 1982; Baltz et al. 1982; Orth et al. 1982; Glova and Duncan 1985; Harn and Kynard 1986). Nevertheless, some fish habitat researchers have employed very simple measures to avoid investigator bias. For example, Probst et al. (1984) and Cunjak and Power (1986) observed fish positions while diving along predetermined zig-zag transects. Extensive discussions of various sampling strategies can be found in Southwood (1978), Green (1979), Johnson and Nielsen (1983), and Bovee (1986). The statistically effective sampling strategies these authors recommend should be used when possible. However, even when time and effort constraints prohibit application of elaborate sampling strategies, simple measures can be taken to minimize investigator bias.

The prepositioned area shocker and sampling procedure were specifically developed to minimize fright bias and investigator bias. Use of this sampling approach may be overly costly in terms of effort and time for some studies (Table 2). This study indicates that for small streams and small fish roughly comparable data may be obtained with much more easily used sampling techniques (backpack shocking), as long as predetermined sampling designs are employed. The prepositioned area shocker, however, has some unique advantages not easily provided by other sampling techniques. Data are obtained on all or most fish using each unit of habitat thereby allowing multispecies analyses. Also, by recording physical habitat for all samples, the data needed for computing habitat selection is automatically obtained. In the final analysis, the most appropriate sampling procedure will depend on study objectives and site characteristics, but minimizing fright bias and investigator bias appears essential.

ACKNOWLEDGMENTS

The data used in this study were obtained while I was conducting research supported by the Massachusetts Cooperative Fishery Research Unit at the University of Massachusetts, the National Wildlife Federation, and the Connecticut River Watershed Council. I am especially indebted to Dr. Ed Peters of the University of Nebraska for presenting this work in my place at the Workshop on Development and Evaluation of Habitat Suitability Criteria.

Table 2. Advantages and disadvantages of the sampling procedures used in the study.

Backpack shocking and no sampling design	Backpack shocking on transects	Area shocking on transects
Quick	Quick	Time consuming
Investigator bias evident	No investigator bias	No investigator bias
Fright bias evident	Fright bias evident	Fright bias minimized
Single species data	Single species data	Multispecies data
Habitat selection difficult to obtain	Habitat selection can be obtained	Habitat selection automatically obtained

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QUESTION AND ANSWER SESSION

Mark Bain
(by Ed Peters)

Li: I have two comments. First, the pattern of sampling (systematic sampling across a transect with sample locations at the edges, one-fourth of the way across, and at the middle) means that each side of the bank will be sampled more intensively than the rest of the river. Second, by folding the prepositioned area shocker in half (for use in small rivers), I am not sure that the electrical field is cut in half.

Peters: It is not covering the same area though.

Li: I am not sure. If you fold an area shocker in half, I am not sure that the area sampled is cut in half. You still have the same area of exposed electrode deployed and all you have done is to change the space occupied by the sampler.

Hampton: I have some questions about that substrate rope. How was the substrate code determined for each portion of the rope? How does that work?

Peters: A particular substrate code is assigned to each 10 centimeter portion of the rope.

Leonard: I think that the technique for using the standard deviation as as an estimate of substrate heterogeneity for determining substrate preferences is a good one. My question is, how would you use that in the physical habitat simulation? I mean, it is not typical of the codes that are used with PHABSIM.

Peters: I don't know how to use that. Ken, do you have any suggestions?

Bovee: I don't know either. In fact, I brought up the same issue in Information Paper Number 21. (Addressing Peters) I wanted to ask you a question though. It is the same thing I asked Mark (Bain). He said the effective limit for using this device is around three feet, which is just about where water starts lopping over the top of your waders. I was wondering if you had any experience in deeper water and how the depth effects the performance.

Peters: The problem that we have had using it in deeper water, with the higher velocities and low visibilities that we have is that we can't be sure that we are collecting all the fish. We have tried putting a block net at the downstream end and it has not worked very successfully in water over about three feet deep. When you start getting higher velocities, you really have a challenge to pick up those fish, either before they drift behind something where you are not going to find them, or when they have recovered by drifting out of the field. Once again, when you have turbid water conditions, you don't know what you have rolling along the bottom.

Leonard: How do you work in that deeper, faster water? How do you get out and pick up these fish? I wonder if it would be possible to use a net with a mouth that could flip up, and then shock toward it.

Peters: One problem we have is finding a mesh size small enough to capture the younger life stages, especially the minnow species. We are working on forage fish on the Platte River, in addition to young-of-the-year channel catfish. They are notorious for staying on the bottom. We literally have to dig them out with a shovel. This has really proved to be a problem. We have gone to using bag seines with additional weight on the lead line to keep it down.

Question from the floor: Do you have a feel for the maximum velocities above which your efficiencies begin to decline?

Peters: Probably about two and a half feet per second. You can't hold a seine in two feet of water if the current is very strong.

Question from the floor: Once you have energized the electrode, aren't you worried about the fish being startled by the netters or escaping from the sampling area before they can be captured?

Peters: Not really. Any fish that is going to be startled will have to go through the highest charged area and would then be most susceptible to being shocked. As with any electrofishing technique, large fish can get up enough momentum to carry them through the field, but it seems that even large fish are rather solidly shocked when they pass over that rather extensive electrode. In our sampling scheme, because of the number of species we have and the difficulty of identifying them in the field, we collect everything and preserve the samples.

Bovee: Ed, in your experience, about how many electrodes can you lay out in sequence before the whole thing turns into a circus?

Peters: Well, you can have the circus with four of them, I suppose. It gets to be confusing when you have a number of plugs all coming to the same place. We have had some embarassing experiences plugging in the wrong electrode. This is funny, because the netters will be all set at one location, you plug in the electrode, and fish start coming up a hundred feet away. That only happens once or twice and then you make sure where everything is. But I would say that any more than six in an area gets to be confusing. Too many electrodes can also create problems with changes in discharge. If someone is changing the flow upstream, by the time you get to the last electrode, it may be high and dry. We have had that happen in many cases.

SELECTION AND USE OF COVER BY SALMONIDS IN EASTERN SIERRA STREAMS: IMPLICATIONS FOR DATA PARTITIONING

by

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INTRODUCTION

The Instream Flow Incremental Methodology (IFIM) (Bovee and Milhous 1978; Milhous et al. 1981; Bovee 1982) is being used to evaluate proposed small hydroelectric and other water diversion projects in California. The hydraulic simulation portion of IFIM/PHABSIM (physical habitat simulation system) is relatively well developed and provides a reasonable simulation of a stream's physical and hydraulic conditions. The fish habitat criteria component of the method, however, is not as well developed. Bovee (1978) and Raleigh et al. (1984) developed probability-of-use and habitat suitability criteria for many of the salmonids. These criteria, however, are based on broad and general information and do not account for the possibility of regional or subspecific variations in microhabitat preference or suitability. Others (Baltz and Moyle 1984; Moyle and Baltz 1985; Gatz 1985; Western Ecological Services Company 1985; David Hanson, EA Engineering, Science, and Technology, pers. comm.) provide information on more specific habitat criteria, but it is unclear if those criteria are appropriate for use in instream needs assessments in the eastern Sierra Nevada. Therefore, a cooperative 2-year investigation was initiated in 1983 by the California Department of Fish and Game, U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, and U.S. Forest Service to develop habitat criteria for brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), and rainbow trout (*Salmo gairdneri*) in the eastern Sierra Nevada region (Smith and Aceituno 1987).

A fish's selection and use of a particular location within a stream is influenced by many factors. Bovee (1982) suggests that the presence or absence of object and overhead cover affects a fish's water depth and velocity selection and that habitat criteria conditioned by the presence or absence of these cover types would provide more meaningful simulations of available habitat through PHABSIM. This report presents information on selection and use of object, overhead, and turbulence cover types by brown, brook, and rainbow trout fry, juvenile, and adult life stages in eastern Sierra Nevada

streams, and discusses implications for data stratification. The influence of associated water depth and velocity on cover type selection and use, substrate use and availability, and spawning life stages is not included in this analysis.

DESCRIPTION OF STUDY AREA

The study area is located in eastern California along the eastern escarpment of the Sierra Nevada mountain range (Figure 1). The area ranges from Owens Lake in the south to near Lake Tahoe in the north; a linear distance of some 150 miles. The region encompasses some of California's most picturesque scenery, ranging from snow-capped 12,000-14,000 ft granite peaks of the Sierra crest to semiarid valleys (3,000-5,000 ft) typical of the Great Basin.

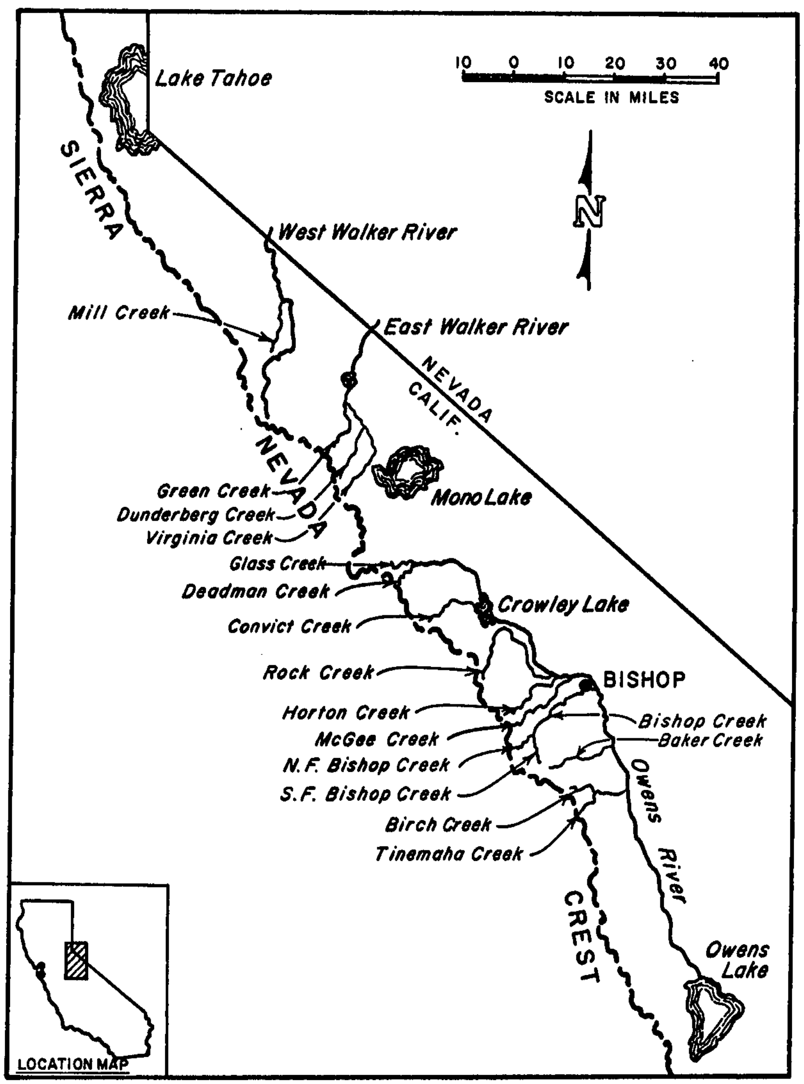

Figure 1. Location of the eastern Sierra Nevada regional fish habitat preference investigation.

Three river systems drain the study area: Owens River, East Walker River, and West Walker River. Most tributary streams in these systems are relatively short and seldom exceed 15-20 miles in length. Stream gradient is typically very steep along the Sierra crest and somewhat less steep in downstream areas as the streams flow down the eastern escarpment. Streams in the study area are typically fed by melting snow packs, and discharge generally peaks during May, June, or July. Low flows occur during winter months.

METHODS

STREAM SELECTION

The numerous streams within the study area were stratified by several criteria, and representative streams were selected from these strata. Selection criteria included: (1) fish species present, (2) similarity to other eastern Sierra streams, (3) potential for hydroelectric or other development, (4) presence of naturally reproducing fish populations, and (5) fish population structure and abundance. Streams and stream reaches sampled were considered to be at or near carrying capacity. Areas that were heavily fished or had received supplemental stockings prior to or during the investigation were not sampled. Eighteen streams were selected for sampling (Table 1). Streamflow is regulated on five of the study streams (South Fork and Middle Fork Bishop, McGee, Rock Creek, and lower Owens River) for power generation, water supply, or agricultural purposes. All streams, with the exception of lower Owens River, are subject to high discharges and fluctuating discharges accompanying rapidly melting snowpacks or periodic cloudbursts. Elevations of the sample areas ranged from 4,400 ft (Tinemaha Creek) to 9,400 ft (North Fork Bishop Creek). Stream reaches sampled contained the full range of habitats available in eastern Sierra Nevada small to medium streams. Larger systems (i.e., Owens River, East and West Walker rivers) were not included in the investigation.

Table 1. Streams and stream sections sampled for cover type use and availability, eastern Sierra Nevada, Inyo and Mono counties, California, 1983-85.

Mill Creek	Owens River	Bishop Creek
Green Creek	Upper	North Fork
Dunderburg Creek	Lower	Middle Fork
Virginia Creek	Convict Creek	South Fork
Glass Creek	Rock Creek	Baker Creek
Deadman Creek	Horton Creek	Birch Creek
	McGee Creek	Tinemaha Creek

SAMPLING TECHNIQUES

The direct underwater observation technique was used to determine cover types used by brown, brook, and rainbow trout. This technique employed two-person teams: an in-water observer and a support/recorder. The observer moved upstream and back and forth across the stream channel until a fish was encountered, at which time species, size (total length), and cover type present were recorded. A 6-inch ruler was used to estimate fish size. Data were not recorded for disturbed fish. The support/recorder followed well behind the in-water observer to avoid disturbing fish. Cover types recorded were as follows:

1. No cover: Observed fish was not associated with object or overhead cover.

2. Object cover: Observed fish's position was influenced by a physical object that provided a shield from or reduced the water velocity. Object cover need not be in the immediate vicinity to be considered present.

3. Overhead cover: Observed fish was under an object that provided overhead protection from predation, sunlight, etc. Submerged objects and objects within 18 inches of the water surface were considered overhead cover.

4. Object plus overhead cover: Combinations of the two cover types.

5. Turbulence: Entrained air sufficient to generate a bubble screen and provide a fish overhead cover or protection from predation, sunlight, etc. Turbulence was considered independently of the above cover types.

For purposes of this analysis, no cover, object, overhead, and object plus overhead cover types are referred to as physical cover types.

Cover type availability was randomly assessed each sample day. Fifty points were selected within each stream section sampled, and cover type present within an "observation cell" was assessed and recorded. An "observation cell" consisted of a 1-ft^2 area about the sample point. Aceituno et al. (1985) and Smith and Aceituno (1987) provide additional information on sampling techniques.

DATA ANALYSIS

Cover type use and availability were partitioned by individual species life stage as follows:

1. Fry: less than 2 inches TL.
2. Juvenile: 2 to 6 inches TL.
3. Adult: greater than 6 inches TL.

Cover type availability data were partitioned by species life stage observed each sample day to assess habitat selectivity. For example, habitat availability observations were included in the brown trout fry available habitat data base only for sample days and areas when brown trout fry were observed. If brown trout fry were not observed, the daily habitat availability observations were not included in compilation of habitat availability and subsequent assessment of cover type selectivity by brown trout fry. However, if more than one species or life stage was observed, habitat availability observations from that sample day were included in compilation of habitat availability and subsequent assessment of cover type selectivity for each species and life stage observed.

Physical cover types and turbulence were considered independently and in combination in the general assessment of no cover/cover preference demonstrated by the three species. Preference for specific physical cover types (no cover, object cover, and overhead cover) and turbulence was considered independently in this analysis. Turbulence was not considered a form of overhead cover.

To assess avoidance or preference of a cover type by a species life stage, electivity for each cover type was calculated using the formula of Jacobs (1974):

$$E = \frac{r - p}{(r + p) - 2rp} \qquad (1)$$

where E = electivity

r = cover type i proportional use

p = cover type i proportional availability

Electivities ranging from 0 to ± 0.25 were considered no preference; +0.25 to +0.50, moderate preference; greater than +0.50, strong preference; -0.25 to -0.50, moderate avoidance; and greater than -0.50, strong avoidance (Moyle and Baltz 1985).

In addition to calculating preference indices, the statistical significance (α = .05) of the proportional differences of cover type use and availability was assessed using the formula of Fleiss (1981):

$$Z = \frac{(r - p) - (1/2n)}{\left(\frac{(p)(1 - p)}{n}\right)} \qquad (2)$$

where Z = standard normal value

r = cover type i proportional use

p = cover type i proportional availability

n = species life stage sample size

RESULTS

A total of 3,277 observations of cover types used by brown, brook, and rainbow trout was recorded during 1983 and 1984 in the eastern Sierra Nevada. Brown trout was the most numerous species observed (1,660 fish), brook trout next (920 fish), and rainbow trout last (697 fish). Relatively few fry were observed--129 brown, 36 brook, and 74 rainbow; juvenile and adult life stages were more abundant.

Habitat availability observations made during the 2-year investigation totalled 3,150. Individual species life stage habitat availability observations range from 635 for rainbow trout fry to 2,064 for brown trout adult (Table 2). Daily habitat availability observations were included in the assessment of cover type use and selection by individual species life stages only if a specific species life stage was also observed during the same sample day and at the same sample location.

Table 2. Number of brown, brook, and rainbow trout observed and available cover type assessments, eastern Sierra Nevada fish habitat criteria investigation, 1983-1985.

	Species					
	Brown trout		Brook trout		Rainbow trout	
Life stage	Habitat use	Habitat available	Habitat use	Habitat available	Habitat use	Habitat available
Fry	129	849	36	711	74	635
Juvenile	868	1,985	470	1,325	399	1,650
Adult	663	2,064	414	1,275	224	1,435
Total	1,660	-	920	-	697	-

The number of habitat use and availability observations per species life stage and cover type was highly variable. The number of observations of specific habitat used for no cover, object, or overhead cover types ranged from 4 (brown trout fry--turbulence) to 720 (brown trout juvenile--no turbulence) (Tables 3-5). The number of available habitat observations range

from 68 (brook trout fry--overhead cover) to 1,298 (brown trout juvenile--no turbulence).

Table 3. Number of brown trout and available habitat observations partitioned by life stage and cover type, eastern Sierra Nevada habitat criteria investigation, 1983-1985.

Cover type	Fry Habitat use	Fry Habitat available	Juvenile Habitat use	Juvenile Habitat available	Adult Habitat use	Adult Habitat available
No cover	24	246	196	569	118	606
Object	34	235	298	570	119	571
Overhead	5	92	103	188	71	201
Object and overhead	66	276	271	658	275	676
Turbulence	1	215	148	687	237	708
No turbulence	128	634	720	1,298	426	1,356

The proportional use and availability of areas with no cover, physical cover, and turbulence cover types indicates that selection and use of cover by trout in the eastern Sierra Nevada is variable and inconsistent. In general, however, all life stages of the three species preferred areas with some form of cover over areas without cover. This is particularly true for brown and brook trout. With the exception of juvenile brown trout, the life stages of these two species demonstrated moderate preferences for areas with physical cover types (Figure 2). Juvenile rainbow trout demonstrated a moderate preference for areas with some form of physical cover, whereas fry and adults did not exhibit any preference and used cover and no cover areas essentially in proportion to their relative abundance. Results of the Z-test indicate that the differences between proportional use of physical cover types, by all brown and brook trout life stages and juvenile rainbow trout, and physical cover's proportional availablity were significantly different. Use of areas with or without some form of physical cover by rainbow fry and adults was not significantly different from its proportional availability.

Although turbulence was not included in the assessment as a specific overhead cover type, I did include it in the general assessment of use of areas with and without cover. When turbulence is included as a form of cover, the electivity indices are virtually consistent with the indices attained

Table 4. Number of brook trout and available habitat observations partitioned by life stage and cover type, eastern Sierra Nevada habitat criteria investigation, 1983-1985.

Cover type	Life stage: Fry		Juvenile		Adult	
	Habitat use	Habitat available	Habitat use	Habitat available	Habitat use	Habitat available
No cover	4	194	72	404	57	380
Object	5	177	121	317	104	303
Overhead	8	68	58	134	76	132
Object and overhead	19	272	219	470	177	460
Turbulence	3	327	210	604	215	582
No turbulence	33	384	260	721	199	693

Table 5. Number of rainbow trout and available habitat observations partitioned by life stage and cover type, eastern Sierra Nevada habitat criteria investigation, 1983-1985.

Cover type	Life stage: Fry		Juvenile		Adult	
	Habitat use	Habitat available	Habitat use	Habitat available	Habitat use	Habitat available
No cover	18	177	57	496	60	433
Object	36	176	156	391	66	365
Overhead	5	55	46	191	29	146
Object and overhead	15	225	140	572	69	491
Turbulence	3	250	123	581	77	504
No turbulence	71	385	276	1,069	147	931

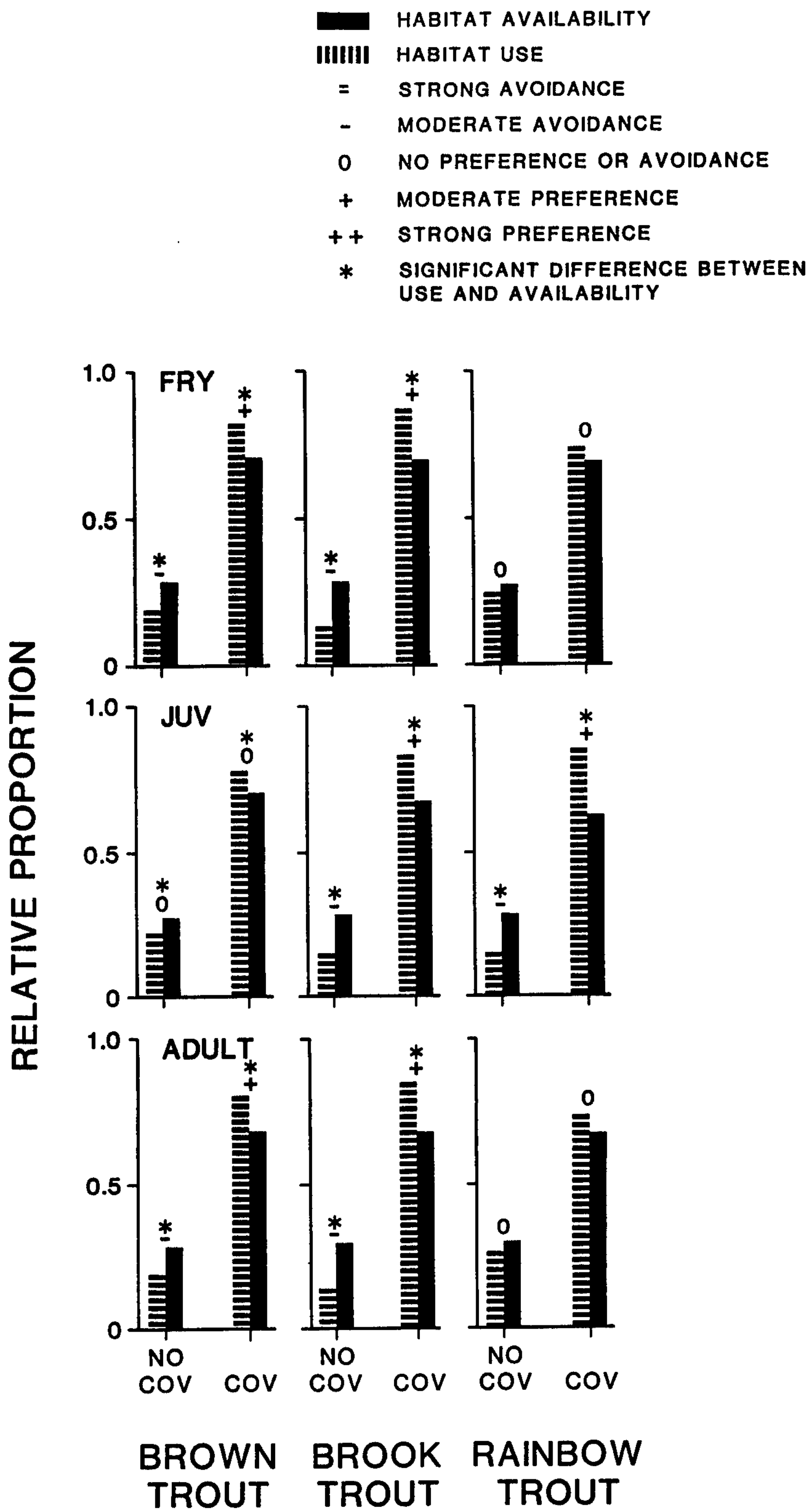

Figure 2. Relative use and availability of no cover and physical cover types by brown, brook, and rainbow trout in the eastern Sierra Nevada.

without considering turbulence. The only exception was brown trout fry changing from moderately preferring areas with cover to demonstrating no preference. Results of the Z-test for significant differences between proportional use and availability, however, demonstrated more varied results. Brown fry and juveniles and brook fry, which demonstrated significant differences between cover use and availability when turbulence was not included in the analysis, did not demonstrate a significant difference in proportional use and availability of areas with or without cover when turbulence was included as a form of cover.

Review of the proportional use and availability of the individual physical cover types indicates that brown trout fry moderately avoided areas of no cover and overhead cover, moderately selected for areas with object and overhead cover, and used object cover proportional to its relative abundance (Figure 3). Juvenile and adult brown trout demonstrated little preference or avoidance of the physical cover types and, with the exception of a moderate avoidance of no cover conditions by adults, generally used the physical cover types in proportion to their relative abundance. Preference and avoidance of entrained air turbulence, however, was considerably more apparent. Fry strongly avoided areas of turbulence and, conversely, strongly preferred areas of no turbulence. Juveniles moderately preferred areas with no turbulence, and adults did not demonstrate a preference or avoidance for turbulent areas.

Brook trout fry moderately avoided areas of no cover and object cover, moderately preferred areas that contained overhead cover, and strongly avoided areas with turbulence (Figure 4). Similar to fry, juvenile and adult brook trout also moderately avoided areas of no cover. However, with the exception of a moderate preference for overhead cover by adults, juvenile and adult brook trout demonstrated little preference for the cover types assessed and used all other cover types (including turbulence) proportional to their relative abundance.

Rainbow trout demonstrated the least amount of cover type preference or avoidance of the three species examined. Rainbow fry moderately preferred areas with object cover, moderately avoided areas with object and overhead cover, and used no cover and overhead cover areas in proportion to their relative abundance (Figure 5). Like brown and brook trout fry, rainbow trout fry also strongly avoided areas with turbulence. Other than a moderate avoidance of no cover areas and a moderate preference for areas with object cover by juveniles, juvenile and adult rainbow trout used all other cover types in proportion to their relative abundance.

The three species examined demonstrated the most noticable and consistent selectivity for use of turbulence and no turbulence. Even though entrained air turbulence is abundant in the eastern Sierra Nevada, few fry of the three species were observed in the presence of turbulence, resulting in a strong avoidance factor for turbulence and a strong selection for areas of no turbulence. Avoidance of turbulence, however, may not be due to fry avoiding turbulence, but rather it may be due to small fish with poor swimming abilities avoiding the fast water velocities typically associated with turbulence. Juvenile and adult life stages of the three species did not demonstrate the same preference or avoidance of turbulent/nonturbulent areas as did fry and, with the exception of brown trout juveniles moderately preferring nonturbulent

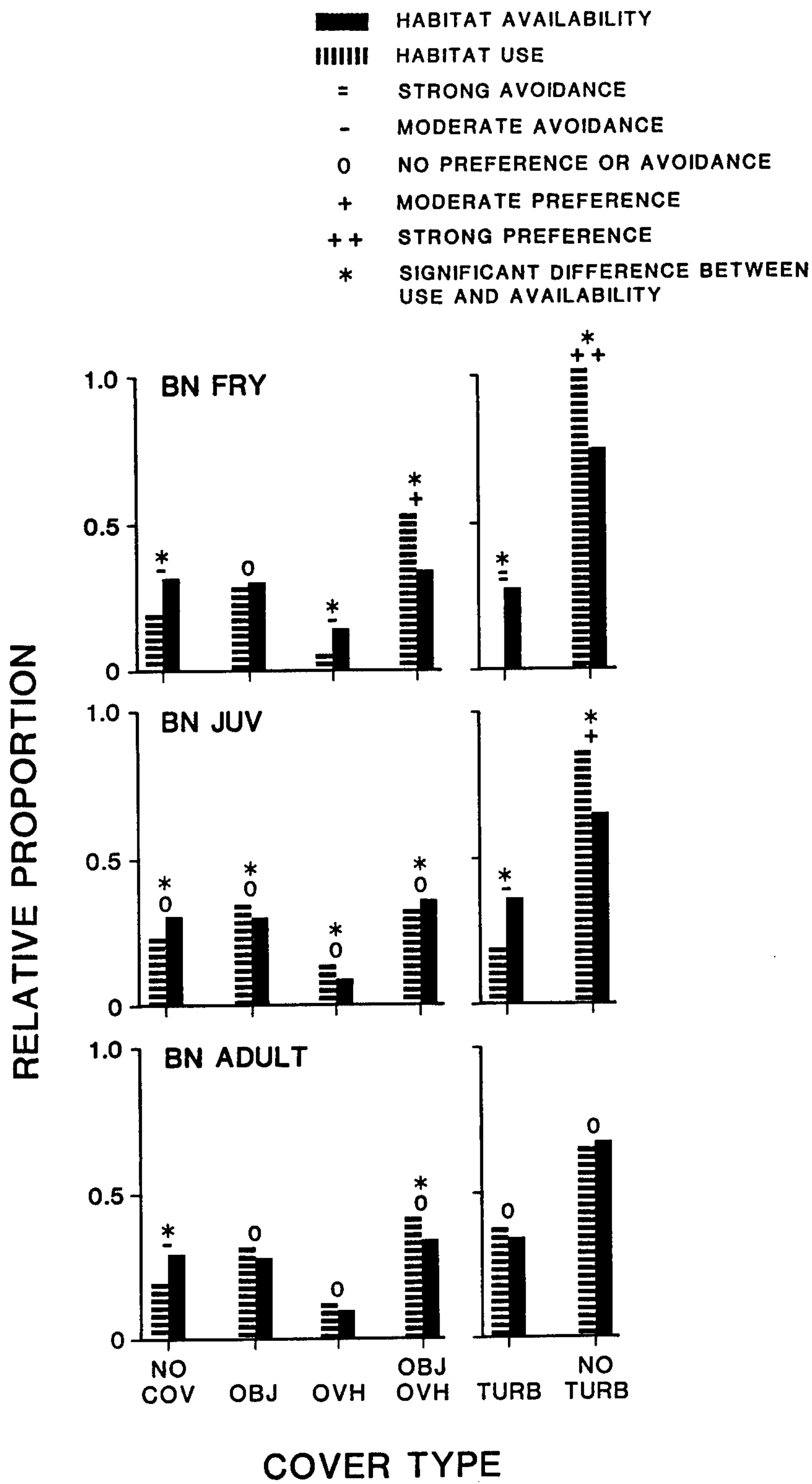

Figure 3. Relative use and availability of no cover, and object, overhead, object plus overhead cover, and turbulence by brown trout in the eastern Sierra Nevada.

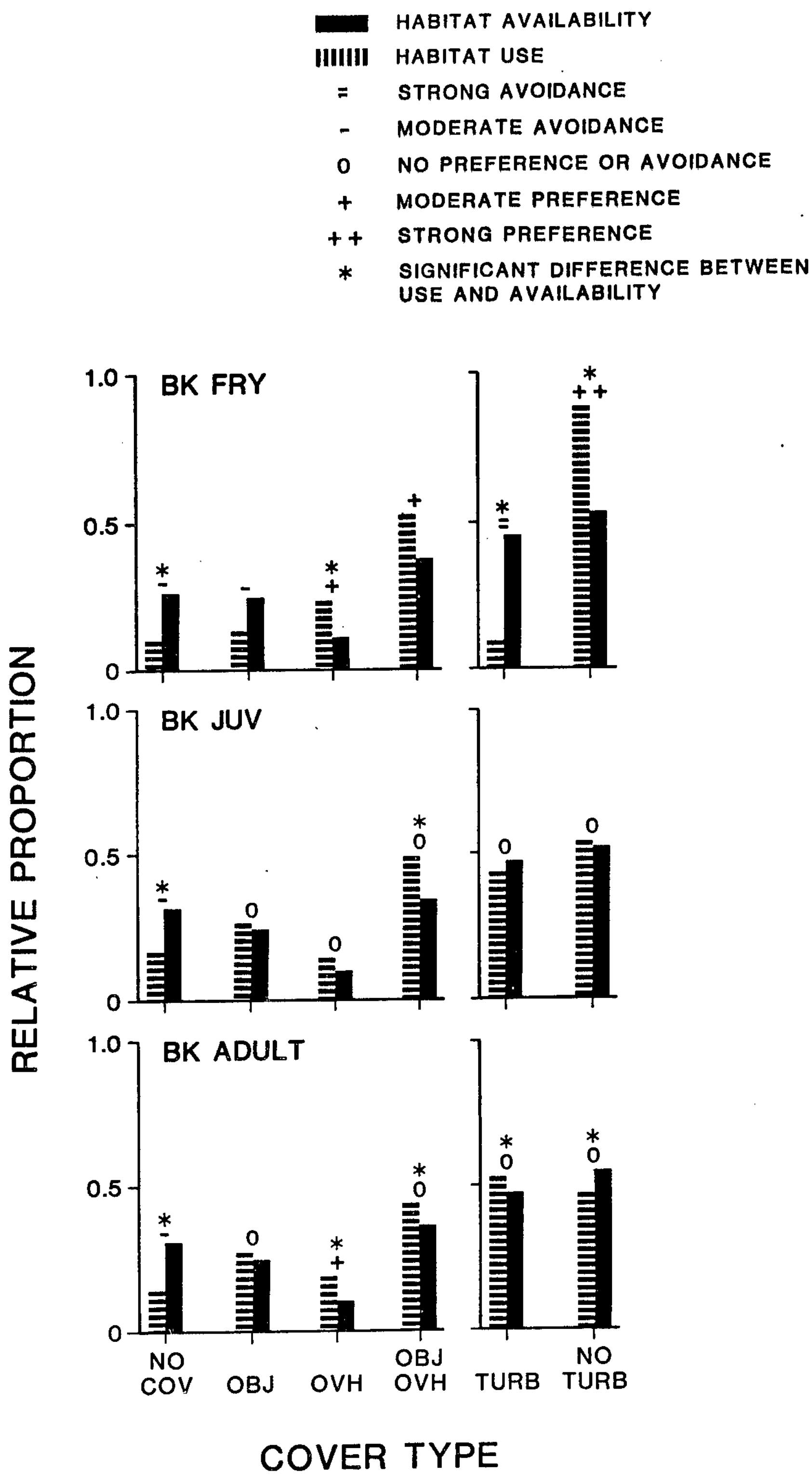

Figure 4. Relative use and availability of no cover, and object, overhead, object plus overhead cover, and turbulence by brook trout in the eastern Sierra Nevada.

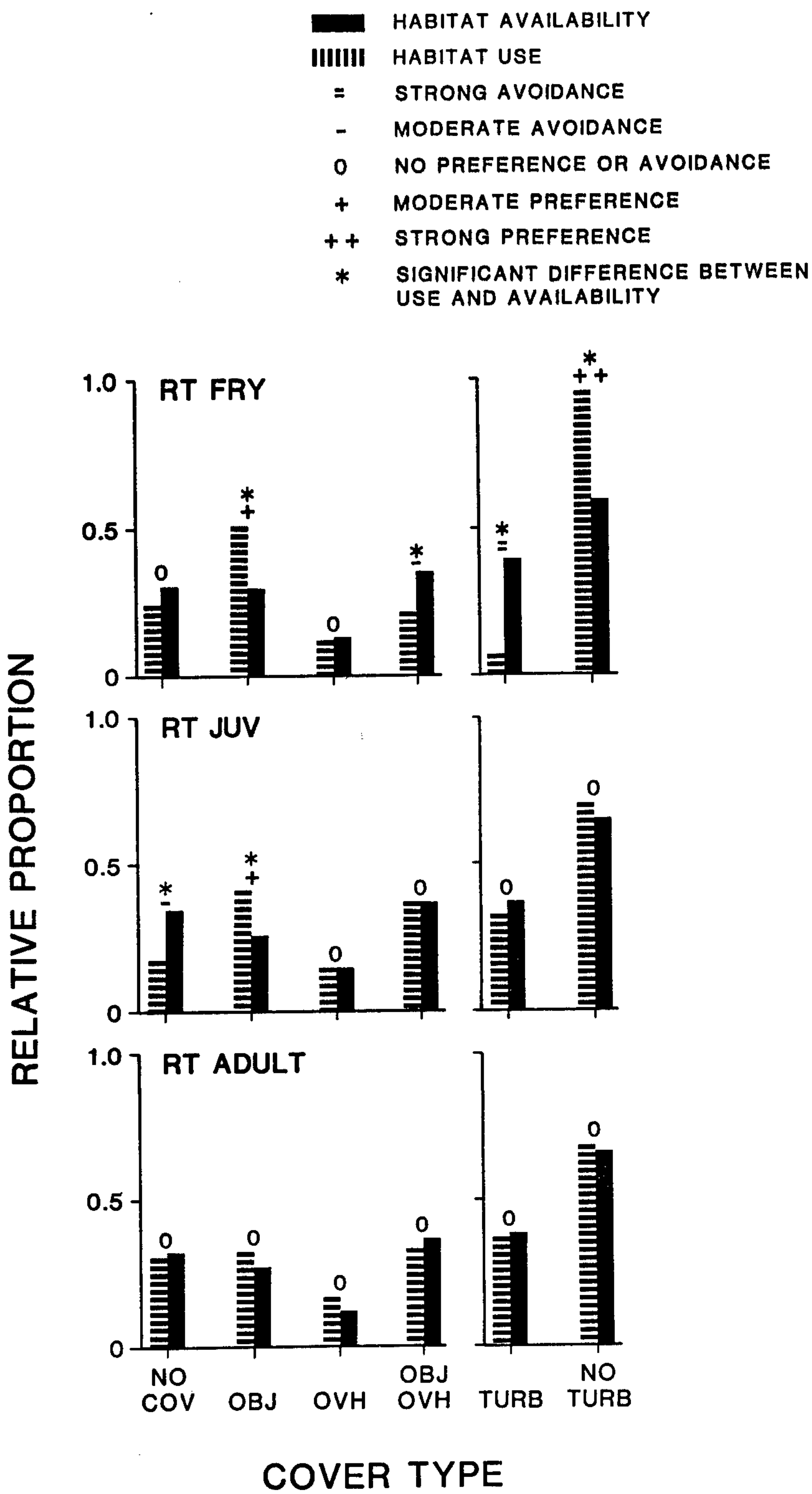

Figure 5. Relative use and availability of no cover, and object, overhead, object plus overhead cover, and turbulence by rainbow trout in the eastern Sierra Nevada.

areas, used entrained air turbulence essentially relative to its proportional abundance.

Testing for significant differences in proportional use and availability of individual physical cover types yielded somewhat different results than those attained through electivity indices analysis. Virtually all the differences in proportional use and availability, of the physical cover types and turbulences for species life stages which demonstrated moderate or strong preference or avoidance of a specific cover type, were significant. Only brook trout fry moderate avoidance of areas with object cover and moderate preference for areas with object and overhead cover were not significantly different from those cover type's relative availabilities. In addition to the differences with moderate or strong indices being significant, a number of species life stages that demonstrated no preference for a specific cover type demonstrated significant differences in proportional use and availability when tested. This was most apparent with brown and brook trout, where the differences in proportional use and availability of a number of cover types was significant, but the electivity indices demonstrated no preference. Rainbow trout did not demonstrate a similar difference between the electivity indices and results of the Z-test--proportional use and availability of no preference cover categories were not significantly different.

DISCUSSION

Review of the results of this investigation provides insight into the need and value of partitioning brown, brook, and rainbow trout habitat criteria by presence or absence of physical cover types for use in IFIM/PHABSIM analyses. The fry, juvenile, and adult life stages of these three species typically demonstrated decided preferences or avoidances of the physical cover types evaluated. Thus, although the interrelationships between water depth and velocity and cover type use or avoidance were not specifically examined, this investigation indicates that water depth and velocity habitat criteria should be partitioned to account for the influence of physical cover types on fish habitat use, preference, and availability. However, study results also indicate it is unnecessary to partition habitat criteria by the presence or absence of entrained air type turbulence.

In addition to data partitioning implications, results of this analysis indicate that the arbitrary preference/avoidance criteria used in this report and by Moyle and Baltz (1985) may be too liberal.

Results of the Z-test for significant differences between habitat use and availability indicated that many differences that demonstrated "no preference" based on the arbitrary ranking of electivity indices were indeed statistically significant. Thus, it is apparent that evaluation of electivity indices based on arbitrary criteria should be approached with caution and that such assessments generally should be for demonstrative purposes only.

Although it was not a specific objective, results of this investigation also provide insight into the need and value of obtaining and using information

on habitat availability as well as habitat use when developing habitat preference or selectivity indices. Without including information on habitat availability in the analysis, study results would have provided information only on frequency of use of the various cover types and not on relative importance of specific cover types. It would have been impossible to develop meaningful information on whether a species life stage was selecting for or against a cover type, and to determine if there is a need to partition habitat criteria by cover type. Thus, the procedure of including habitat availability in development of habitat criteria is useful, since it uncovers habitat needs and preferences not readily apparent through use data only.

In summary, selection and use of physical and turbulence cover types by brown, brook, and rainbow trout in the eastern Sierra Nevada was variable, but the three species generally preferred areas with some form of cover to areas with no cover. The importance of individual cover types (no cover, object, overhead, object plus overhead, and entrained air) was also variable, but sufficient differences occurred to justify partitioning habitat criteria by the physical cover types. Electivity indices indicate fry life stages generally select for or avoid the various cover types, whereas juvenile and adult life stages of the three species generally use cover types in proportion to their relative abundance. Many of the differences between a species life stage's proportional use and a cover type's relative availability (including those with indices that indicated no preferences) are statistically significant. Entrained air turbulence appears to be relatively unimportant to larger fish as a form of overhead cover, but fry of the three species consistently avoid areas with this type of turbulence. Avoidance of air entrained water, however, may be more the result of the small fish avoiding fast water velocities typically associated with turbulence rather than specifically avoiding the turbulence.

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QUESTION AND ANSWER SESSION

Gary Smith

Jean Caldwell: Do you think that given unlimited time and money, you could do some kind of analysis of the fish's use of water velocity shear zones? Do you think that the relationship between fish and shear zones may change existing habitat criteria and, thus, influence PHABSIM analyses?

Smith: Yes, given unlimited time and resources. I think including shear zone information in criteria development likely would influence criteria development and resultant PHABSIM analyses. Unfortunately, we didn't collect information on shear zone use of proximity during our eastern Sierra investigation so we cannot explore the value of shear zones with our existing data base. However, shear zones appear to be important to trout for a variety of reasons. We often observed fish closely associated with but not in shear zones. These fish were near shear zones, but were in slower velocity areas. Undisturbed, these fish periodically venture into and through the shear zone into faster water velocities, capture food items, and return to their initial location. On the other hand, when disturbed, the fish often darted into the faster velocity areas and used the entrained air turbulence typically associated with shear zones in eastern Sierra streams or overhead cover to escape.

Question from the floor: Have you considered developing separate criteria for different times of the day?

Smith: Yes we have, but to do so would require a data base considerably larger than we have since the data would have to be stratified by time of day. One thing that we have noticed from a fish behavioral standpoint is that brown trout in the eastern Sierra are far more active in the water column after sunlight strikes the stream than before. Almost at the instant the sunlight hits the water surface the fish move from interstitial chambers in the substrate up into the water column. I am not sure what causes this phenomenon. It does not appear to be related to abrupt water temperature changes or changes in food item availability.

Question from the floor: Based on your experience with the study, do you think it is a good idea to stratify criteria according to cover type?

Smith: Absolutely. Based on the results of this study I belive there is sufficient evidence to justify partitioning or stratifying habitat criteria by cover type.

Question from the floor: Have you developed information on cover type use and selection for each stream you sampled and looked for similarities and differences? Have you compared the results of the eastern Sierra investigation with information from other systems?

Smith: The criteria that were developed for the Tahoe streams are similar to the criteria for the Sierra streams. The areas are similar, but the streams are just a little dissimilar. The gradient in the Tahoe basin is a little steeper. The velocity tends to be a little higher and the discharge tends to be a little flashier. Also, there are some streams in the Tahoe basin that have only brook trout in them.

THE ROLE OF PROFESSIONAL JUDGMENT IN THE DEVELOPMENT OF CATEGORY I CRITERIA CURVES

by

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INTRODUCTION

Category I criteria curves are descriptions of the behavioral responses of fish based on information other than site-specific field measurements. This includes professional judgment, life history descriptions in the literature, and curves developed from other streams. While it is preferable to develop site-specific (category II or III) criteria, constraints imposed by time, budgets, availability of species of interest, or the physical characteristics of the stream frequently necessitate the use of category I curves. Category I curves are often criticized because of the reliance on professional judgment, however, professional judgment plays a role in the development of all types of curves. The role of professional judgment is simply more explicit with category I criteria.

METHOD

The development of category I criteria entails obtaining available behavioral information on the species and lifestages of interest, summarizing pertinent information in an easily reviewable format, evaluating this information with fellow biologists, and constructing the best possible curves based on behavioral information in reference to the stream of interest.

Behavioral information can be obtained from a variety of sources. In addition to libraries and agency data files, an investigator should contact colleagues in the geographical area to turn up additional references. The National Ecology Research Center, Aquatic Systems Branch, maintains a library of both published and unpublished information for a wide variety of species.

Through this process, a considerable amount of information of sometimes questionable value will be accumulated. Much of the information may not refer to behavioral responses and will be of little value. Some will contain general descriptions of habitat preferences (e.g., "Steelhead spawn in riffles at the end of pools."), and perhaps observed ranges and means of utilized depths and velocities. Some will contain criteria curves, but little documentation regarding their development. Finally, a precious few references will contain curves, the raw field data, descriptions of the physical characteristics of the stream, and the field and data analysis methods used.

Summarizing the pertinent information in an easily reviewable format can be as simple as graphing available curves for each lifestage onto clear acetate for use on an overhead projector. Each curve can be drawn in a different color and labeled as to its source. Along with the overhead slides, a list of references should be prepared that includes a brief description of how the curve was developed. Where possible, the geographic location, numbers of field observations, method of observation, range of available depths and velocities, discharge at the time of measurement, stream gradient, hydrologic regime and width, and other pertinent information should be noted. This information is extremely useful when evaluating the quality and applicability of the curves for the particular stream of interest.

Those references that contain only minimum and maximum or optimum values can be displayed in tabular form. This summary sheet can be referred to when discussing the left and right end points of the curves.

Once all the information is summarized, it should be distributed to the appropriate biologists.

After the interested parties have had a chance to review the summarized information, a meeting should be held to discuss the data. The goals are to reach understanding and agreement about the levels of data quality and the applicability of each reference curve to the stream of interest. It is helpful to have all the original reports and references available for review when questions arise. As the meeting or meetings progress, many of the references will be determined to be unreliable and/or inappropriate for the stream of interest. The remaining references, along with professional judgment, can then form the basis of the category I curves ultimately developed.

Theoretically, all parties will agree on which references are both reliable and appropriate, and the shape of appropriate curves will be obvious. In reality, there will be disagreements, particularly when one or more parties has already developed curves independently. All parties will tend to defend their proposed curves and may argue that the references that tend to support their curves are the most reliable and appropriate. This situation is further complicated by the difficulty in identifying reliable and appropriate curves

and by different parties having different responsibilities and goals relating to curve development.

EVALUATING REFERENCES

Numerous factors must be considered during an evaluation of a curve reference. Some factors may be addressed in the reference itself while others can only be answered by speaking with the original author. Often the original author will not be available and questions regarding methods may remain unanswered. In these situations the value of the data may be severely compromised. Factors to be considered include but are not limited to the following.

SAMPLING METHOD

The sampling method used by the original investigator will influence the data and any resulting curves. Electrofishing may displace fish from their usual positions, whereas seining may not allow an investigator to discriminate between habitat types. Direct observation is usually preferred, but wading and snorkeling also have limitations.

SEASON

Seasonal changes in fish behavior patterns are commonly recognized in the literature. Summer and fall daytime measurements are usually well represented. Little information is available on nighttime or winter fish behavior.

FIELD CONDITIONS

Physical and morphological constraints such as turbid water, white water, or lack of safe access may constrain observations to a limited set of habitat conditions.

MORPHOLOGICAL CHARACTERISTICS

This consideration does not relate to the quality of the data, but to its appropriateness. Assuming the data in question were collected in an acceptable manner, was the population of fish similar in size and run timing to the population on the stream of interest? Is the river similar in hydrologic regime, gradient, and geographic region?

STUDY OBJECTIVES

The purpose of the original study may have constrained the original field or analysis methods. For instance, one popular reference in Washington State

contains spawning observations of 4 salmonid species from 22 Washington streams and rivers. Without a clear indication from the authors, one could postulate seasonal, equipment, or personnel limitations that perhaps put less emphasis on seeing all habitats available and more emphasis on getting data from a range of streams.

DATA ANALYSIS

Where the original data are not reported, the method of data analysis becomes particularly important. The treatment of outliers or the interpolation for missing data intervals can dramatically change the shape of a curve.

MANAGEMENT PRACTICES

Most fish species are of interest because of their commercial or recreational value. Past or present management practices can affect the applicability of literature data. A stream managed as a put-and-take fishery may support fish that have different behavioral responses than wild stock. Heavy stocking and harvest of anadromous species may dilute river-specific characteristics.

COMING TO AGREEMENT

Although a myriad of factors confront investigators trying to evaluate references, eventually the search-and-review process will reach a point of diminishing returns. The next step, discussing references and curves in an open forum to reach agreement, also presents an array problems. While many of these problems are related to the quality and applicability of the available data, others stem from the policies and responsibilities of the reviewing parties. Examples of both types of problems are presented.

SON AND DAUGHTER CURVES

Often an investigator will take comfort in finding a number of references that appear to follow a general pattern. Many times such curves are actually based on the same set of field data, reworked by different investigators over the years. In evaluating these curves it is all too easy to assume the values are independent, rather than to recognize the interrelationship of the data sets. All reviewers need to be made aware of this situation whenever it occurs.

PRIDE OF OWNERSHIP

Often a biologist involved in the curve development process has personally collected a portion of the field data being evaluated. Even if problems with the data are evident, the biologist may prefer to weigh this data set heavily

during discussions. The other biologists present may be less than excited about this data set, and conflicts can develop. Tact, rather than biological insight, may be the key to resolution of this problem.

SIZE OF RIVER

Many biologists would agree that the size of the river is a factor to be addressed in an evaluation of references. Though there may be agreement on this general concept, the size of the stream in question can be surprisingly difficult to agree on. A river may routinely pass large flood events (which affect the channel shape and size), but an upstream water control project may severely restrict average flow conditions. Whether the river size should be determined by existing flows, historical flows, channel conveyance, or some other criteria may be difficult to resolve.

VARIED FLOW CONDITIONS

It is not uncommon to find data collected on controlled streams with diurnal flow variations. Measurements taken during a regular 24-hour power-peaking regime may have little biological relevance. If the biologist who collected the data was aware of this problem, and spread field observations over the 24-hour period including night hours, the results may be useful to review. Talking to the biologists who actually collected the field measurements can be of great help in reviewing such data sets, and their comments should be available to all reviewers.

DOCUMENTATION

Another pitfall in literature curve review is documentation, or rather the lack of it. During tenser parts of a negotiation, undocumented curves can exacerbate the professional judgment problem. Before the curve-specific discussions take place, it is helpful to agree on whether undocumented curves will be reviewed at all.

PROFESSIONAL JUDGEMENT

The amount of usable site-specific field data for many rivers is small. Much of the agency biologists' criteria for assessing curves and literature data sets comes from casual observations that represent years of experience on rivers. In cases where there is threat of litigation, consultants may be reluctant to use this kind of "collective experience," preferring to rely heavily on field measurements collected in some kind of proper, defensible format. Reliance on "common knowledge" has drawbacks, such as the potential over-influence of outliers in setting ranges ("I once saw a fish spawn 10 feet deep in the Black River, therefore . . ."). On the other hand, considering measurements collected during an out-of-basin PHABSIM study as patently more acceptable than the collective experience of the local biologists can create considerable problems during negotiations.

Resource agency biologists feel strongly that because agencies are charged with the responsibility of managing the resource, they should have the final say on the biological tools used in that management. The agencies as a group usually have extensive experience with fish behavior and biology, which are the basis of criteria curves.

In the case of category I criteria, stream-specific information is usually lacking or insufficient. In such instances, agency biologists usually take a conservative approach and propose curves that encompass all potential site-specific fish preferences. These "broad" curves are intended to ensure full protection of the resource, and they are assumed to contain the actual fish preferences if they could be determined.

When working with consultants, it sometimes becomes apparent that these agency goals are not given proper credit. There is often a a perception among the agencies that their collective experience is not given credence similar that accorded actual measurements. While the agency biologists' experience may be stream-specific, often the fish measurements under discussion, good as they may be, are not from the specific geographic areas under discussion. Agency biologists often feel their judgment regarding appropriate criteria curves should be weighed at least as heavily as non-site-specific data.

Biologists representing the project proponent may have a different perspective on the question of whose professional judgment should prevail. In many cases, it is the consultants who are familiar with the available data on a particular species and have read and summarized much of the available reports. This position of familiarity with the literature can make the consultants feel that theirs' is the best opinion on which curves are most appropriate. In situations where the literature conflicts with the professional judgment of agency biologists, the consultants may feel more comfortable with the literature data. This can lead to the consultants taking the position that data from a number of well-conducted studies from another geographic area should take precedence over the unquantified opinion of local biologists.

The conflict between these two perspectives can be seen in the question of "broad" (conservative) curves. Frequently, agency proposed curves are intentionally shifted towards greater depths and velocities, presumably containing the true site-specific preferences. The consultants may believe the curve should be narrowed down to an assumed site-specific preference. The broad curve may fulfill the agency's responsibility of being conservative on the side of the resource, but may not fulfill the consultants' perceived responsibility to develop site-specific curves based on data that can be defended in court. In these cases, the question of who has the right to decide can be problematic for both parties.

There is no easy solution for these problems. Even collecting site-specific data may simply move the discussion to differences of interpretation. If a large effort is to be made to review the literature, and if new information will be brought to agencies or consultants for review, we recommend that none of the parties involved propose curves until discussion and review of the all available information is finished. This will allow all parties to freely

incorporate new information if it is judged appropriate, without sacrificing a perceived negotiating position. Also, time set aside specifically for technical discussions will be less likely influenced by negotiations, and all parties may at least start from a common point of understanding.

If the question of who makes the final decision cannot be clarified beforehand, another recommendation would be to have the option of "agreeing to disagree" as one of the possible outcomes. The option of running two different sets of preference criteria through a PHABSIM modeling process is expensive and may add confusion to the process of analyzing results. It can also increase resentment or suspicion of the PHABSIM process by decisionmakers. Usually this possibility is so horrible to contemplate that when faced with it, amazing compromises can be reached.

QUESTION AND ANSWER SESSION

Jean Caldwell
Phil Hilgert

Question from the floor: If you wanted to use discharge to stratify criteria from small rivers versus large rivers, would you want to use the discharge during the spawning period, or would you use something like mean annual flow?

Hilgert: There are many ways to stratify streams to come up with the best data set. The problem is, when you start stratifying, you may end up with one data set in each stratification.

Caldwell: I agree with you, but I don't know what the best technique would be. I think you have to pay attention to the processes that determine channel shape and not get so fish-oriented that you forget what created the stream channel.

Hilgert: Generally, I would agree that the mean annual flow or the one-in-two year flood flow is a good way to look at the size of the river. But, if there is a relationship between the size of river and shape of curve, and an indication that the postproject flows are going to be a lot lower than the baseline flows, I think you may be biasing and introducing error into the results by using criteria for a large river. The differences may not be large, but if you are trying to develop a flow regime where the postproject river is actually smaller than the existing river, it may be advisable to use criteria for a small stream.

Bruya: But don't the criteria to be used define the postproject flow, and therefore, the size of the river?

Hilgert: If you are looking only at the technical aspects of developing instream flow requirements.

Caldwell: This issue can be a major source of disagreement because one argument could be the assumption of "no project." The other argument assumes the project as a baseline condition.

Smith: How long did this whole process take to resolve the differences?

Hilgert: In total, we have been in negotiations for nearly a year.

Smith: The reason that I asked is that we (California Fish and Game--eds.) are asking water development proponents to evaluate existing criteria and the consultants are depending heavily on the existing criteria. We have not had much success in convincing anyone to conduct field verification studies, to date.

Hilgert: In our situation, a field verification study will be difficult. For example, what are the effects of a depressed run size on the results of a verification study? Furthermore, in some streams there is the problem of visibility of less than two inches. Another problem is that the last two years in Washington have been extremely low-water years. If we had even had river basin specific data, we could have gone a longer way towards resolving this problem. We could have avoided some of the hassles, but I am not sure we could have gone all the way.

Bruya: It is obvious (from the presentation) that there are two curves. One that the agency developed and one that the consultants developed. There doesn't appear to be any agreement. What is going to happen is that an evaluation is going to be made based on both curves. And eventually a decision is going to be made and that decision is going to be made by either an agency administrator, division chief, regional director, or a judge. My question is, did anybody involved in this process consider the fact that the final decision was not going to be made by a biologist? The decision is going to be based on political aspects. Was that considered?

Caldwell: I think it is safe to say that it was a storm cloud hanging over all of us while we were trying to do this because we knew that.

Bruya: But this didn't have any bearing on the biologists trying to achieve a consensus?

Caldwell: No, it has a lot of bearing on it. The point I am trying to make is that we are trying to get together, but we were given totally different objectives, and we can't always reconcile the objectives. If I knew then what I know now, I would have said, "Let's not go through this whole approach." But, unfortunately, given the FERC regulations and the consultations, my agency says that we can't do that. We would look like we were not cooperating.

Aceituno: That bothers me because it gets the agency and the biologist off the hook. Then they can both say, "Well, we were right and the decisionmaker just made the wrong decision."

Caldwell: I felt bad about that too, because in lots of cases, it is not going to be who is right or who did the best job, it is going to be whoever does the best graphics.

Bovee: Recalling the two velocity curves you showed, why didn't you just average the two and get it over with?

Caldwell: We did that on one of the rivers that is not likely to go before an ALJ (Administrative Law Judge--eds.).

Bovee: Even if it went before an ALJ, that is probably what he would do too.

Hilgert: If it were not going before an ALJ, you may have reviews coming from outside the agencies and they may say, can you defend that compromise? What does that compromise mean? Is that compromise costing the rate payers money? And if you can't defend it, are they going to try to throw it out? So a compromise may not be the most defendable action.

Question from the floor: But isn't negotiation a matter of compromise anyway? When you have two weighted usable area curves and you are trying to come up with the best flows, isn't there a negotiation process involved?

Caldwell: That is true, but it is nice to keep the biology in it as long as possible before you start negotiating.

Question from the floor: But both sides are at a stopping point now, aren't they?

Hilgert: No, we are not at a stopping point. If it were a simple stream we would run both curves to see what impact they have on the results. If there is no difference, it doesn't make any difference which curve we use. Our problems are not restricted to existing criteria.

Caldwell: We are still fighting over which hydraulic simulation programs to use.

Hilgert: And we want to look at including cover for juveniles, but not including cover for spawning, so we have two different criteria sets for those. We are trying to define the substrate criteria based on a ten category distribution rather than lumping them all into one, which means we have three sets of substrate criteria for each study site for each life stage of each species.

Crance: What would likely have happened if you had each done five years worth of study to come up with those curves? Do you think that curve would have been any different than the ones you have up there?

Caldwell: I think we would have resolved most of the differences.

Hilgert: Having two sets of curves is like having two uncalibrated thermometers. You never know which one is right. However, we generally compromise for site-specific information, and for studies which may not be under close scrutiny. We take the approach of locking the door and nobody leaves until we have one curve.

Crance: You could have done the same study yourself and come up with two different results like that.

Brad Caldwell: I think one thing to notice about the curves too, is the fact that you are dealing with a generic river that you are unable to do any kind of verification on because of the nature of the river. If you look at all the curves on the graphs you showed, you will notice that a lot of them have narrow peaks. And there are two distinct sets. One set goes up quickly on the left and then comes down, and after that one has come down, the other one starts up, peaks, and comes down. So you are really talking about a left hand group of curves and a right hand group. The question is, which one is right? When you don't know anything about the river, do you make a curve that covers both of them or do you have to pick one of them? I would suggest that if it is definitely a stream, pick the one on the left, and if it is definitely a river, pick the one on the right.

Caldwell: And we have already discussed that we don't really know what it is.

Brad Caldwell: That is why this is kind of a unique problem.

Hilgert: It may be unique in some respects, but keep in mind that as you develop category I curves, you are going to come upon these same problems. Maybe not all of them on the same project, but many of them on any project.

Nelson: I find it interesting that you would even consider tailoring curves to postproject conditions.

Caldwell: One of the reasons, Pat, is that that project has been in there since 1914. While the postproject minimum flows may not be the minimum flow that we would set now, the project is a fact of life.

Hilgert: With a new project, you generally go with the present size of river being mean annual flow. But there are some situations where you may want to look at other ways of determining the size of the river.

Nelson: So you can't make the assumption that the preferences of a species for velocity and depth are universal?

Hilgert: I am not sure anybody would say that the preferences for depth and velocity for an anadromous species are universal. Many people think that each run has specific characteristics, as well as regional specific characteristics.

Question from the floor: Basically, what are you doing about your responsibilities as a consultant in describing the existing conditions?

Hilgert: Our responsibility was to develop a PHABSIM study. My client was directed by FERC to develop a specific PHABSIM study. This is only one part of a much larger ongoing investigation which takes into account addressing those requirements.

Li: Because the historical flow releases from the existing project are so low, should that change anything from the kind of perspective and the kind of charge that you are placed with?

Caldwell: I think it changes a few things. It definitely affects the stream hydrology. The fact that the project has released a very low minimum flow for a long period of time has affected the fishery quite seriously. These are what I consider to be physical and biological effects. Then, there are the institutional effects: Washington State versus tribal treaty rights. The probability of a major lawsuit is high, and lawsuit paranoia is pervasive. It all gets back to the question of whether this river is a big river or a small river because it has been held to such a low minimum flow.

Hilgert: The specific biological question that I was going to add is that if you have two curves, one developed in a big river and one in a small river, do you want to use the big river curve to define instream flow requirements if the realistic project flows are more typical of a small river?

RESULTS ON THE USE OF THE DELPHI TECHNIQUE FOR DEVELOPING CATEGORY I HABITAT SUITABILITY CRITERIA FOR REDBREAST SUNFISH

by

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ABSTRACT

A Delphi exercise, consisting of four rounds with 11 experts as panelists, was conducted (by correspondence) to develop Habitat Suitability Criteria (HSC) for redbreast sunfish, Lepomis auritus. The exercise resulted in category I HSC for velocity, depth, substrate, cover, and temperature.

INTRODUCTION

The need for Habitat Suitability Criteria (HSC) for use in evaluating environmental changes in streams has been well established (Smith 1973; Bovee and Cochnauer 1977; Stalnaker 1979; Bain et al. 1985; Glova and Duncan 1985; Moyle and Blatz 1985; Sheppard and Johnson 1985). Bovee (1986) defined the term "microhabitat suitability criteria," identified three categories of HSC, and presented guidelines for the development of HSC for use with the Instream Flow Incremental Methodology (IFIM). The category number refers to the procedure used to develop the criteria. Category I HSC are based on professional judgment, with little or no empirical data. Both category II (utilization criteria) and category III (preference criteria) HSC use microhabitat data collected at locations where target species were observed or collected. The development of category II and III criteria for all species of concern would be ideal. Measuring the specific habitat of fish (especially fish that inhabit turbid, deep, or very swift streams) challenges conventional sampling methods (Larimore and Garrels 1985), however, and may not be economically or technologically feasible. In the absence of habitat utilization or habitat preference criteria, category I HSC should be useful for decisionmaking regarding water management. The purpose of the paper is to describe how the Delphi technique (Linstone and Turoff 1975; Delbecq et al. 1975) was used to develop category I HSC for redbreast sunfish.

The Delphi Technique

Delphi was the name of a meeting site in ancient Greece where Oracles (people through whom a deity was believed to speak) met, held discussions, and gave wise or authoritative decisions or opinions. The modern day Delphi, a technique used for developing a consensus among experts, was first applied to strategic planning by the United States Air Force during the early 1950's. Subsequently, the methodology was widely accepted and applied in corporate planning (Fusfeld and Foster 1971) and used in the field of renewable resources management (Ludlow 1972a,b; Zuboy 1981; Heller et al. 1983). More recently, it has been used to develop category I HSC for a number of fish species, including: striped bass, *Morone saxitilis* (Crance 1984); American shad, *Alosa sapidissima* (Stier and Crance 1985); paddlefish, *Polyodon spathula* (Crance 1987a); Atlantic sturgeon, *Acipenser oxyrhynchus*;[1] shortnose sturgeon, *A. brevirostrum* (Crance, 1986); sauger, *Stizostedion canadense*[1]; and redbreast sunfish, *Lepomis auritus*.[1]

Basically, a Delphi exercise is an anonymous polling of expert opinion, with the goal of reaching a consensus. The concept is based on the premises that (1) opinions of experts are justified as inputs to decisionmaking where absolute answers are unknown, and (2) a consensus of experts will provide a more accurate response to a question than a single expert.

Expert opinion may be obtained in a number of ways, e.g., correspondence, face-to-face meetings, telephone, computer terminals. Regardless of the communication method used, the basic elements are (1) a group of experts who are willing to participate, and (2) a monitor or monitoring committee that selects panelists, designs appropriate inquiries, evaluates responses, summarizes results, and serves as the primary source of information for clarifying questions that arise. The general procedures are (1) the experts are polled on a question or series of questions, (2) the responses are tabulated, analyzed, and fed back to the experts, and (3) the experts reanswer the questions in light of the information generated by the aggregate responses. This process is repeated until a consensus is reached. Anonymity of the experts is maintained, at least until the exercise is completed.

A typical Delphi exercise to develop Habitat Suitability Criteria would operate as follows. A group of experts is identified. The objectives and procedures of the exercise are explained to each expert. Agreement to participate as a panelist is obtained. Each panelist gives his opinion or estimate on the inquiry. The results, including rationale given by each panelist, are summarized and fed back to each panelist, ending the first iteration or round. Panelists answer the inquiry again, in light of the information generated by the collective response to Round 1. This process is repeated until a consensus or acceptable level of agreement is reached. The exercise is terminated (usually after four or five rounds) and the procedures

[1]An unpublished completion report on the results of a Delphi exercise conducted to develop HSC for this species is available from the National Ecology Research Center.

and results are documented, including all rationale for agreement or disagreement, if any. More detailed guidelines for using the Delphi technique to develop habitat suitability index curves are available in Crance (1987b).

THE REDBREAST SUNFISH DELPHI EXERCISE

The range of the redbreast sunfish extends from New Brunswick south, east of the Appalachian Mountains, to central Florida, west to the Apalachicola River; apparently, they are not in Mississippi, but have been introduced into Texas and Oklahoma (Scott and Crossman 1973; Carlander 1977). The species uses a variety of ecological conditions and habitats from sea level to at least 1,345 m elevation, including headwaters, streams, coastal plain rivers, and lakes (Shannon 1967). It is a highly prized sportfish in North Carolina (Davis 1971) and throughout most of its range. In spite of its popularity, little is known about its habitat requirements, and few HSC for the species are available. Personnel in Region 4, U.S. Fish and Wildlife Service, identified the need for category I SI curves for redbreast sunfish, in 1985. A Delphi exercise, consisting of four rounds, was conducted by correspondence during January-September 1986, to develop SI curves for the species.

Methods

Selection of panelists. The selection of panelists was started by compiling a list of names of individuals considered to be experts on or highly knowledgeable about redbreast sunfish. I contacted each person on the list by phone and discussed the objectives of the proposed Delphi exercise, explained the Delphi process, and asked the following questions: Do you feel comfortable being considered by your peers as an expert on this species? Whom do you consider to have a lot of experience with, or to be highly knowledgeable about, habitat of the species? Would you agree to serve, without compensation, as a panelist for the proposed Delphi exercise? Names of individuals considered to be redbreast sunfish experts were added to the list of potential panelists. This process was repeated for each potential panelist and resulted in a list of about 15 experts, 11 of whom served as panelists throughout the exercise (Table 1).

Round 1. Round 1 was started by mailing each panelist an information packet, which included a letter confirming participation as a panelist (Appendix A), background information on the Delphi technique and the development and use of SI curves, instructions (Appendix B) for completing the round, some preliminary definitions of terms (Appendix C), and a query to elicit opinions on the importance of cover (Appendix D).

Panelists were first requested to consider the relationships between habitat suitability for each major life stage and activity (e.g., spawning incubation, larva, juvenile) of the species occurring in lotic habitat, using velocity, depth, substrate, cover, temperature, and other variables considered to be critical to the well-being of the species (Appendix B). Next, panelists were requested to record their preliminary opinions of these relationships,

Table 1. Panelists for a four-round Delphi exercise to develop habitat suitability criteria for the redbreast sunfish.*

Gray Bass Florida Game and Freshwater Fish Division Holt, FL 32564	Dick Luebke Texas Parks and Wildlife Department Heart of the Hills Research Station Junction Star Route, Box 62 Ingram, TX 78025
Dan Crochet South Carolina Wildlife and Marine Resources Department Route 8, Box 5-A Florence, SC 29501	Donald Orth Department of Fisheries and Wildlife Sciences Virginia Polytechnic Institute and State University Blacksburg, VA 24061
James R. Davis North Carolina Wildlife Resource Commission Box 998 Elizabethtown, NC 28337	John S. Ramsey Cooperative Fish & Wildlife Research Unit, Department of Animal Ecology Iowa State University Ames, IA 50011
David Etnire Department of Zoology University of Tennessee Knoxville, TN 37996-0801	Monte E. Seehorn U.S. Forestry Service 508 Oak Street NW Gainesville, GA 30501
Dan Holder Georgia Department of Natural Resources 108 Darling Avenue Waycross, GA 31501	Jay Stauffer School of Forestry Resources Pennsylvania State University University Park, PA 16802
Robert B. Hudson Biology Department Presbyterian College Clinton, SC 29325	

*Participation as a panelist in this exercise by these people does not imply endorsement of the results.

using tables designed to elicit responses (Appendices E-H). They were encouraged to comment on and give ideas, logic, and references pertinent to their estimates, and to use "gut" feelings in the absence of data or if they disagreed with available data.

Panelists were requested to respond to Round 1 and subsequent rounds within 10 to 14 days. A shorter response time appeared to be unrealistic. A

few panelists called me (before responding) to clarify instructions and the meaning of some terms. If a panelist did not return his estimates within 14 days, he was contacted and encouraged to respond as soon as possible. A summary of the round, which included each panelist's comments on each curve, a tabulation of estimates of variable values, and a set of preliminary SI curves, was prepared within about 2 weeks after receipt of the responses. Some comments and supporting statements were slightly revised, if necessary, to preserve anonymity. The preliminary SI curves were based on a composite of the panelists' estimates. The median of the estimates for each variable and life stage or activity resulting from the first round were used as the coordinates for the preliminary curves used for Round 2. Results of the first round query on cover suitability (Appendix D) were summarized in tabular form (Appendix I) for use in Round 2.

Round 2. Round 2 was started by requesting each panelist to (1) review the summaries of the first round, (2) consider each preliminary SI curve and the cover SI's in light of any new information at hand, and (3) indicate agreement or disagreement for each curve and SI. If a panelist disagreed with any SI or segment of a curve, he was requested to indicate his version of the SI or curve, including the x and y coordinates for the end points of the curve and the optimum range, and then provide comments, ideas, references, logic, and "gut" feelings to support his version. If he agreed on the preliminary SI or curve, he was encouraged to give reinforcing comments.

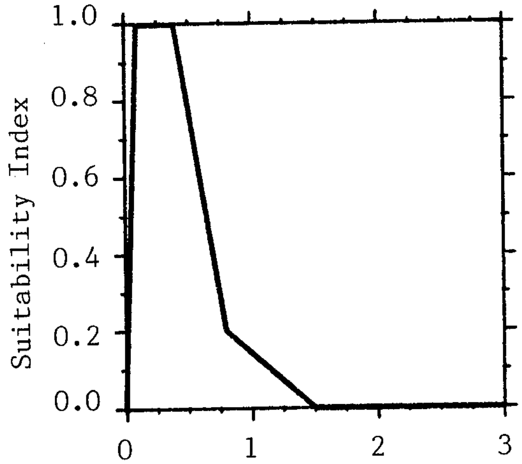
Round 3 and Round 4. Instructions for Round 3 called for each panelist to consider any modified curve or SI in light of new information and to indicate agreement or disagreement on each curve or query. This process was repeated through Round 4 when a general consensus among panelists was reached. The exercise was then terminated, and pertinent comments and disagreements, if any, were recorded for each curve or SI.

Results

The Delphi exercise resulted in two velocity SI curves (Figure 1), three depth SI curves (Figure 2), two substrate SI graphs (Figure 3), three temperature SI curves (Figure 4), two cover SI curves (Figure 5), and 28 suitability indices for eight cover types (Table 2). Pertinent comments and disagreement, if any, stated by panelists during Round 4 are included with the pertinent SI curve, graph, or table. Table 3 shows an example of how an SI curve evolved during the 4-round Delphi exercise.

Discussion

Potential users of Delphi-generated HSC and representatives of organizations with responsibilities for managing water resources to be evaluated should be involved to the fullest extent possible in decisionmaking relative to development of the criteria (i.e., selection of the species to be evaluated and what criteria are required, when the criteria are expected, identification of experts to serve as panelists, and how the Delphi will be conducted). I endeavored to select panelists that were most knowledgeable about redbreast sunfish habitat preferences. I attempted to avoid overrepresentation by panelists from a single agency, interest group, or geographical location. This did not present a problem because experts on the species are few in



Spawning, Incubation, and Larvae

Coordinates		
x ft/s	x cm/s	y SI
0.0	0.0	0.0
0.1	3.0	1.0
0.4	12.0	1.0
0.8	24.0	0.2
1.5	46.0	0.0

Three panelists disagreed. Comments were: "Disagree. I think 1.5 ft/s is too high for SI=0. I would say SI=0 at 1 ft/s. Assuming lotic habitat only, 0.1 ft/s as minimum optimum velocity seems very reasonable."

"Disagree. I can't imagine a redbreast sunfish building a nest in an area with mean columnn velocity of 1 ft/s, if preferred depths (as we agreed) are 1-3 ft. Those values would occur in runs, not edge pool habitats where redbreast spawn. Data from Davis (1971) represent average cross-section velocity, which would be much higher than in the areas where redbreast sunfish spawn. I suggest these coordinates: 0 ft/s, SI=0; 0 to 0.3 ft/s, S=1; 0.7 ft/s, SI=0."

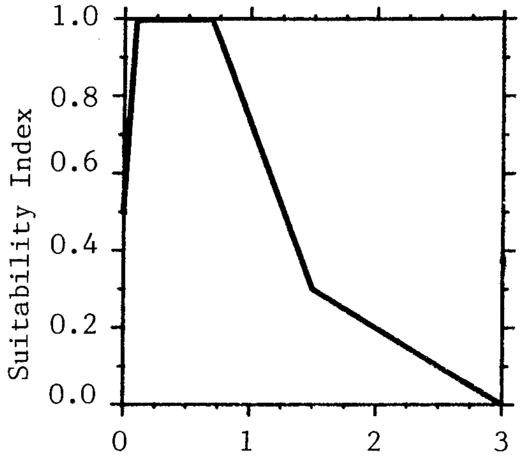
"Disagree. I would give SI=1 for 0.1 to 0.3 ft/s and S=0 at 0.7 ft/s."

"Work by Davis (1971) reflects the stream velocity and not the velocity at nest site. I agree with this curve. In most cases the site is protected by some form of cover. We have redbreast spawning in coastal North Carolina in tidal areas. However, the tidal flow is probably less than 1 ft/sec."

"I think any further changes in the velocity curves will not serve any concrete benefit without sound biological facts."

"I agree if this is velocity at spawning site."

Figure 1. Water velocity (mean column) suitability index curves for redbreast sunfish spawning, incubation, and larvae; and juveniles and adults. Curves resulted from a four-round Delphi exercise conducted by correspondence. Eleven experts served as panelists.



Velocity (ft/s)
Juveniles and Adults

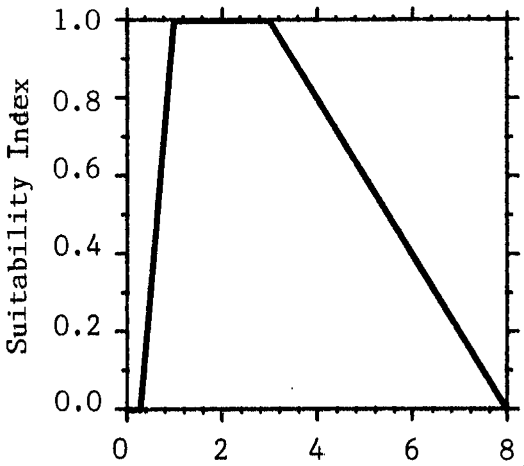
Coordinates		
x ft/s	x cm/s	y SI
0.0	0.0	0.5
0.1	3.0	1.0
0.7	21.0	1.0
1.5	46.0	0.3
3.0	91.0	0.0

One panelist disagreed. Comments were:

"Disagree. First, velocities of 0.0 ft/s are as suitable as 0.1 ft/s, assuming water quality is suitable. Redbreast may prefer areas at the edge of the channel at 0.1 ft/s over stagnant back-waters with 0.0 ft/s velocity, but that may be due to water quality, temperature, or food conditions <u>not</u> current velocity. The whole problem with this curve and our disagreement is that we are trying to develop one microhabitat SI curve to describe the various microhabitats used for different activities. I would certainly not change the optimum range beyond 0.7 ft/s. I would change 0.0 ft/s to SI=1. We are developing these curves to describe redbreast sunfish habitat suitability, <u>not</u> to justify needing more water in our streams."

"Agree. 3 ft/s seems high, but the fish will dart in and out of such velocities to feed."

Figure 1. (Concluded)

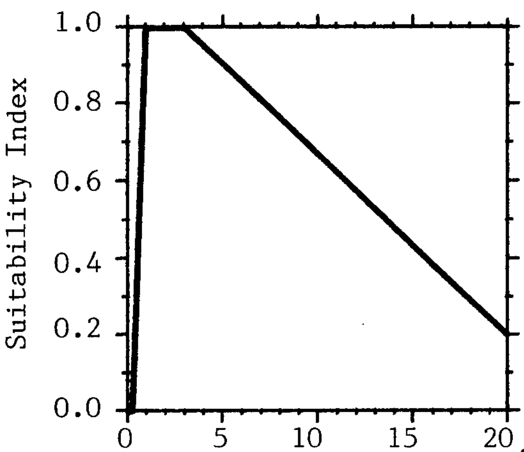


Spawning, Incubation, and Larvae

Coordinates		
x ft	x m	y SI
0.3	0.1	0.0
1.0	0.3	1.0
3.0	0.9	1.0
8.0	2.4	0.0

One panelist disagreed. Comments were:

"I agree with all of the curves except the descending limb. Depth is probably of little significance beyond 2 ft if temperature and substrate are suitable. I would change optimum depth from 1-3 ft to 1-8+ ft."



Juveniles

Coordinates		
x ft	x m	y SI
0.3	0.1	0.0
1.0	0.3	1.0
3.0	0.9	1.0
20.0	6.1	0.2

One panelist disagreed. Comments were:

"There is no logical reason why depths >3 ft should be unsuitable. In the presence of appropriate structure for protection from predators, redbreast would use greater depths. The decline suggests we are confounding the depth curve with the cover curve. Decline in suitability in deep pool habitat is most likely a function not of depth but of less suitable cover, which is described by curve 12 (Figure 5). I would change optimum from 1-3 ft to 1-20+ ft."

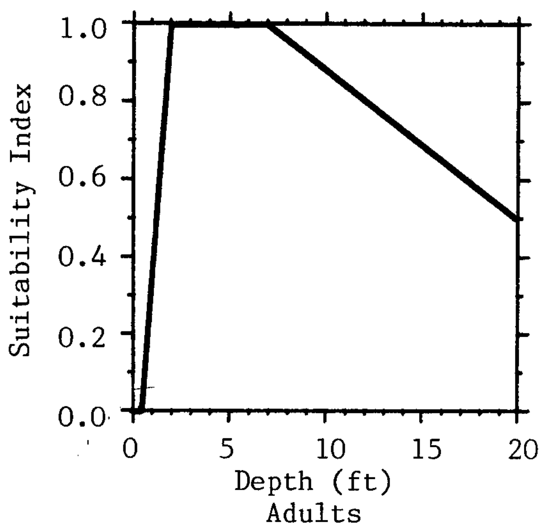
(Comments continued, next page).

Figure 2. Water depth suitability index curves for redbreast sunfish spawning, incubation, and larvae; juveniles; and adults. Curves resulted from a 4-round Delphi exercise conducted by correspondence. Eleven experts served as panelists.

Comments: Water depth - juveniles (continued)

"Agree. I like the unknown maximum depth."

"I agree with the curve but also agree with one of the reviewers that the optimum range may be on the narrow side. However, I have nothing to support or refute changing curve."



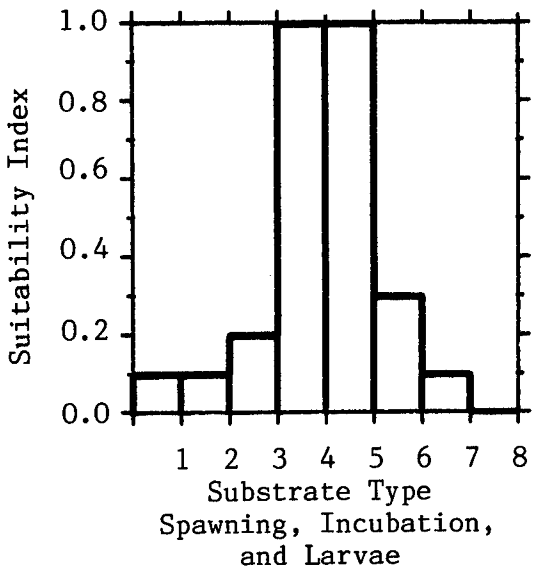
Coordinates		
x ft	x m	y SI
0.5	0.15	0.0
2.0	0.6	1.0
7.0	2.1	1.0
20.0	6.1	0.5

One panelist disagreed: Comments were:

"I disagree with descending limb of curve. I would give SI=1 at 20 ft."

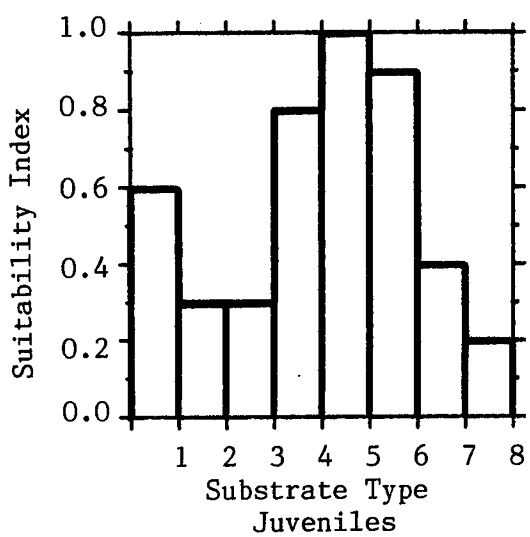
"Agree. I like the unknown maximum depth."

Figure 2. (Concluded)



x (code)	Particle size	y (SI)
1	Plant detritus/organic material	0.1
2	Mud/soft clay	0.1
3	Silt (<0.062 mm)	0.2
4	Sand (0.062 to 2 mm)	1.0
5	Gravel (2 to 64 mm)	1.0
6	Cobble/rubble (64 to 250 mm)	0.3
7	Boulder (250 to 4,000 mm)	0.1
8	Bedrock (solid rock)	0.0

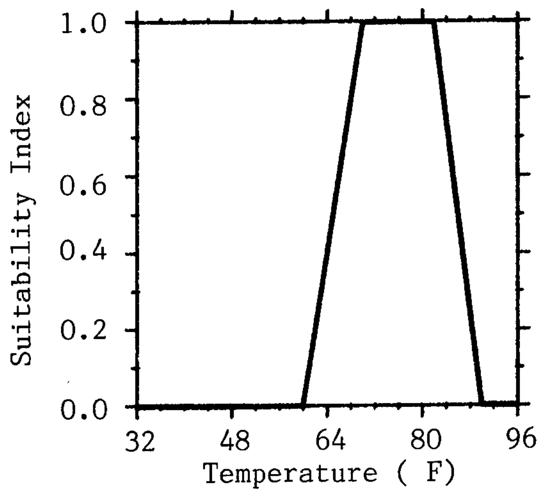
One panelist disagreed. Comments were: "Seems to me that silt would be less desirable than mud/soft clay. I would assign equal value to silt and mud/soft clay but I am not overly concerned since both have low SI values."



x (code)	Particle size	y (SI)
1	Plant detritus/organic material	0.6
2	Mud/soft clay	0.3
3	Silt (<0.062 mm)	0.3
4	Sand (0.062 to 2 mm)	0.8
5	Gravel (2 to 64 mm)	1.0
6	Cobble/rubble (64 to 250 mm)	0.9
7	Boulder (250 to 4,000 mm)	0.4
8	Bedrock (solid rock)	0.2

There were no disagreements or comments.

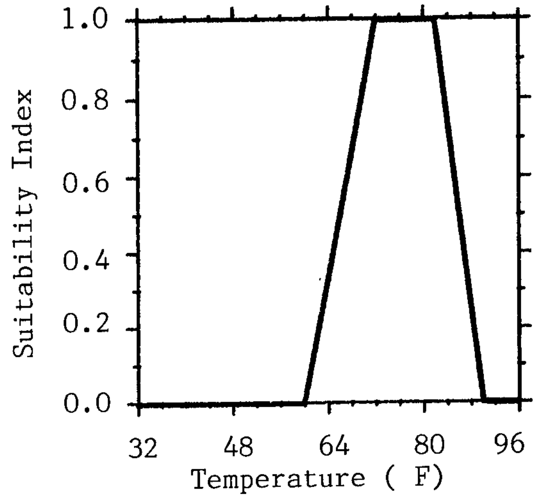
Figure 3. Substrate suitability index graphs for redbreast sunfish spawning, incubation, and larvae; and juveniles. Graphs resulted from a 4-round Delphi exercise conducted by correspondence. Eleven experts served as panelists.



Spawning and Incubation

Coordinates		
x °F	x °C	y SI
60	15.6	0
70	21.1	1
82	27.8	1
90	32.2	0

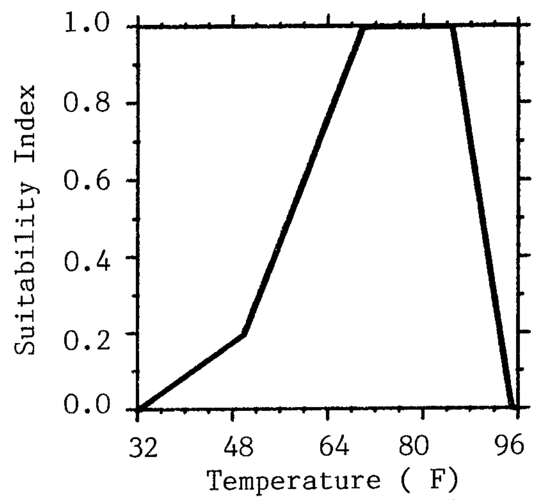
There were no disagreements. Comments were: "Geographical variations may occur but I would not change curve." "Agree, but upper temperatures are still a question mark."



Larvae

Coordinates		
x °F	x °C	y SI
60	15.6	0
72	22.2	1
82	27.8	1
90	32.2	0

There were no disagreements. A comment was: "Agree, but upper temperatures are still a question mark."

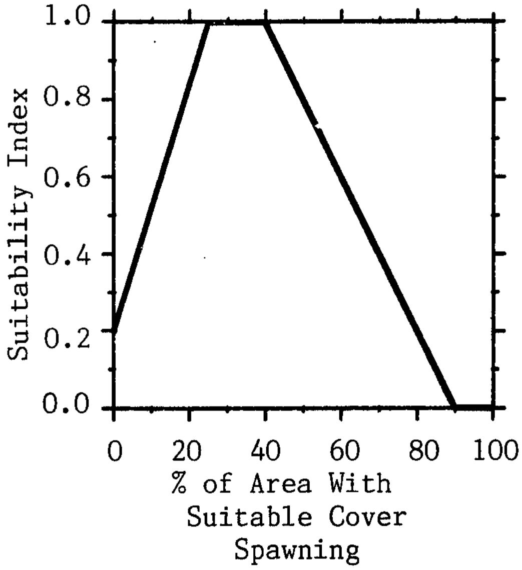


Juveniles and Adults

Coordinates		
x °F	x °C	y SI
32	0.0	0.0
50	10.0	0.2
70	21.2	1.0
85	29.4	1.0
95	35.0	0.0

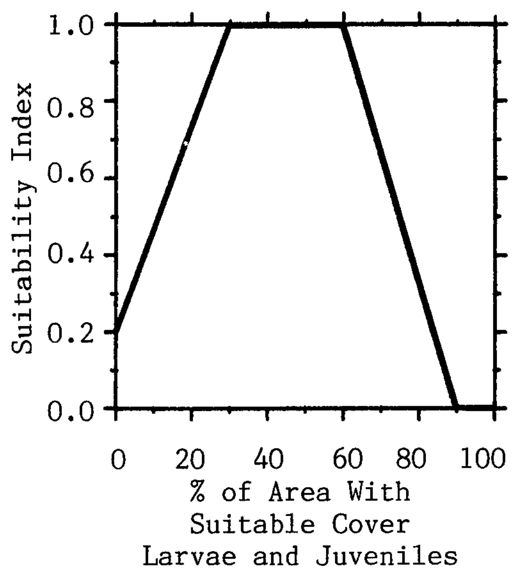
There were no disagreements or comments.

Figure 4. Water temperature suitability index curves for redbreast sunfish spawning and incubation; larvae; and juveniles and adults. Curves resulted from a 4-round Delphi exercise conducted by correspondence. Eleven experts served as panelists.



Coordinates	
x %	y SI
0	0.0
25	1.0
40	1.0
90	0.0

There were no disagreements. A comment was: "I believe spawning can occur without cover (i.e., in a small indented area in stream bank which allows water to collect)."



Coordinates	
x ft	y SI
0	0.2
30	1.0
60	1.0
90	0.0

There were no disagreements. Comments were: "Do we need a curve for adults? The curve we considered during Round 3 for juveniles would serve also for adults. Table 8, which follows, does not quantify cover."

Figure 5. Cover suitability index curves for redbreast sunfish spawning; and larvae and juveniles. Curves resulted from a 4-round Delphi exercise conducted by correspondence. Eleven experts served as panelists.

Table 2. Cover suitability indices (0 = totally unsuitable, 1 = optimum) for redbreast sunfish.[a]

Cover type[b]	Life stage or activity and SI[c]			
	Spawning	Larva	Juvenile	Adult
1. Logs, brush, stumps, snags, cypress roots/knees	1.0 (0.8)[d]	0.8	0.9	1.0
2. Boulders	0.3 (0.2)[d]	0.4	0.5	0.7 (0.9)[d]
3. Large cobbles--small boulders	0.4 (0.2)[d]	0.4	0.8	0.8
4. Gravel-small cobble	0.7 (0.3)[d]	0.9	0.6	0.4
5. Steep banks with overhanging vegetation and willow roots/trees	0.8 (0.6)[d]	0.7	0.6 (0.8)[e]	0.6 (0.8)[f] (0.9)[f]
6. Aquatic vegetation (rooted macrophytes)	0.4	1.0	1.0	0.5 (0.8)[d]
7. Plant detritus/ organic material	0.1	0.5	0.3	0.1
8. Limestone outcrops or overhangs	0.1	0.1	0.6	0.7

[a]Suitability indices resulted from a four-round Delphi exercise conducted by correspondence. Eleven experts served as panelists.

[b]Cover can simply be described as any feature of a stream that provides reduced lighting, reduced velocity, or increased visual isolation. Even more simply, cover is something the fish can either get under or behind. Cover may also provide suitable substrate or habitat for food organisms utilized by the fish.

[c]SI without additional number in parentheses indicates all panelists agreed on SI.

[d]SI in parentheses was considered to be more appropriate by one panelist. Remaining panelists agreed on SI not in parentheses.

[e]Two panelists considered SI=0.8 to be more appropriate than SI=0.6.

[f]One panelist considered SI=0.8 to be more appropriate and another panelist considered SI=0.9 to be more appropriate than SI=0.6.

Table 3. Water temperature (°F) criteria for redbreast sunfish spawning and incubation at the end of each round for redbreast sunfish.[a]

Results at end of round	Low temp. for SI=0	No. panelists disagreeing	Low temp. for SI=1	No. panelists disagreeing	High temp. for SI=1	No. panelists disagreeing	High temp. for SI=0	No. panelists disagreeing
Round 1[b]	Range= 40-70 Median= 60	--[c] --[c]	Range= 60-80 Median= 70	--[c] --[c]	Range= 75-85 Median= 82	--[c] --[c]	Range= 80-95 Median= 88	--[c] --[c]
Round 2	60	1[d]	70	2[e]	82	0	88	1[f]
Round 3	60	1[g]	70	1[h]	82	0	88	1[i]
Round 4	60	0	70	0	82	0	90	0

[a] The Delphi exercise was conducted by correspondence. Eleven experts served as panelists.

[b] The range and median of all estimates given for Round 1. The medians were used to construct the preliminary SI curve for Round 2. The SI curve for spawning was combined with the SI curve for incubation during Round 3.

[c] Not applicable for Round 1.

[d] Panelist suggested changing the temperature to 70 but did not present convincing rationale.

[e] One panelist suggested changing the temperature to 68 and another panelist suggested changing it to 77. Neither panelist presented convincing rationale.

[f] Panelist suggested changing temperature to 90 but did not present convincing rationale.

[g] Panelist suggested changing temperature to 64 but did not present convincing rationale.

[h] Panelist suggested changing temperature to 72 but did not present convincing rationale.

[i] Panelist presented strong evidence that temperature should be changed to at least 90.

number and scattered. Data to support the appropriate number of panelists for a Delphi exercise are not available. A minimum number of eight has been suggested (Hodgetts 1977; Zuboy 1981). I feel that a panel with about 10 experts is ideal. More than 10 may be desirable if interest in the target species is widespread and more than 10 experts are available to participate as panelists. The higher the number of panelists, the greater the effort needed for summarizing reports, typing, contacts, and other necessary logistics.

Implicit and acceptable definitions of relevant terms are needed during a Delphi exercise. Some questions that will likely arise are as follows. Where is water velocity measured? What time of day or which season will the criteria be applicable to? How should food abundance and availability be treated as variables? How do we account for geographic variability in habitat preferences? Are backwater areas of large river reservoirs lentic or lotic? These questions should be resolved to the satisfaction of all participants.

To date, few Delphi-derived HSC for a fish species have been compared to criteria developed from sampling data. Baldridge (1981) compared HSC for spawning pink salmon generated by professional judgement with HSC subsequently generated from analyses of data obtained from sampling pink salmon spawning habitat. Agreement between the sets of criteria was close, which, as pointed out by Bovee (1986), illustrates that true experts can assemble highly accurate habitat criteria using only their experience and intuition.

Some scientists will question the validity and usefulness of the redbreast sunfish HSC. This is expected and appropriate. The criteria represent "average" values of riverine habitat quality for the species and will be useful only for predicting "average" SI's. Potential users of these or any category I HSC should scrutinize the criteria and information base used to develop the criteria and decide their adequacy for a specific need. Delphi-derived HSC or other category I HSC are not replacements for category II or III HSC. However, in the absence of category II or III HSC for redbreast sunfish, I believe that the criteria that resulted from the Delphi exercise have utility for assessing redbreast sunfish riverine habitat. I agree with Bovee (1986) that "decisions regarding water management will proceed regardless of the quality of the biological information, and may be made with no input from the biological community. In view of this reality, category I criteria are vastly superior to no criteria."

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Appendix A. Letter mailed to panelists (11) to begin Round 1 of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

Dear:

Thank you for agreeing to serve as a panelist for the redbreast sunfish Delphi exercise.

The purpose of the exercise is to develop Suitability Index (SI) curves for use with the Instream Flow Incremental Methodology (IFIM) in the assessment of riverine habitat of redbreast sunfish. The Delphi technique is being used because field data and information available in the literature on habitat suitability for the species are inadequate for developing SI curves. Available information on redbreast sunfish will be used in developing the curves, but opinions of the Delphi panelists will be the primary basis for the resultant curves.

General information about the Delphi technique and SI curve development, and instructions and materials for completing the first round of the exercise are enclosed. A few hours of your time will be required to complete the first and subsequent rounds of the Delphi. You, no doubt, have many demands on your time, but please respond to each round promptly. We should complete the exercise in about 6 to 8 months, assuming that four or five rounds will be required and that all panelists respond to each round within 10 days after receipt of material. You may wish to get an associate to serve as panelist in your behalf if you are unable to respond within 10 days.

I will serve as monitor of the exercise. This means that I will prepare the material for each round, summarize responses, and prepare a final report, including rationale for the curves developed. Anonymity among panelists will be maintained until the exercise is completed.

Thank you again for consenting to be a panelist. I look forward to receipt of your input.

Appendix B. Instructions mailed to panelists (11) to begin Round I of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

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1. Consider the relationships between riverine habitat suitability for redbreast sunfish for each of the variables -- velocity, depth, substrate, cover, and temperature. What is the relationship between each variable and habitat suitability for each life stage or activity (e.g., spawning, incubation, larval, juvenile, adult, or other life stage or activity)?

2. Next, fill in the columns of each of the tables (attached). Information that panelists enter in the tables will serve as the basis of SI curves that will be developed by the monitor for consideration during Round 2.

3. List references, data sources, or any information available that you wish to use as the basis of your curve. It is important that you use your "gut" feeling or opinion, even if no data are available. You may choose to ignore all available data or information and use <u>only</u> your "gut" feeling or opinion as the basis of your curve. If you mention a reference to data, please give the complete citation or send the monitor a copy of the report. If the reference has been published in a popular journal or has been widely circulated and is likely available in small libraries, you need not send it.

4. Write comments, ideas, logic, reference, etc., at the bottom of each table or on the reverse of the page.

5. If you feel that a variable or a life stage other than those listed in a table is important and should be considered for an SI curve, please clearly define the variable, explain how the variable is quantified, and give the specific size-group, season or unique life stage/activity the variable applies to.

6. If you have questions, you may call me. Please return your response within 10 days.

Appendix C. Preliminary definition of terms mailed to panelists (11) to begin Round I of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

The redbreast sunfish Delphi exercise will be concerned with the riverine (lotic) habitat used by the various life stages of the species. A definition of some terms likely to be used during the exercise has been assumed. If you disagree with a general definition listed below, please give your definition of the term and/or any other terms that you feel need clarification.

Spawning habitat. Crucial habitat for adults during spawning, including courtship, the release of eggs and sperm, and fertilization.

Incubation habitat. Crucial habitat of eggs during incubation.

Larval habitat. Crucial habitat of larvae from hatching to juvenile stage or while the fish are a specified length or age.

Juvenile habitat. Crucial habitat of juveniles until sexual maturity is reached or while the fish are a specified length or age.

Adult habitat. Crucial habitat of sexually mature fish (excluding spawning activities). If crucial habitat requirements for a particular size, age, or activity differ, specifics are needed.

Appendix D. Cover suitability query mailed to panelists (11) at the beginning of Round I of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

If you consider cover to be important to the well-being of any life stage or activity of redbreast sunfish, please describe what the cover is, how it benefits the fish, how it may be quantified in relation to habitat suitability, what happens if there is more cover, less cover, no cover, etc. Sketch your versions of any cover SI considered to be important. Use the space below and reverse side of page if needed.

Appendix E. Table used to elicit opinions of panelists (11) on water velocity suitability - Round 1 of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

REDBREAST SUNFISH - DELPHI ROUND 1 - WATER VELOCITY

Panelist ____________ Date ________

Complete this table by filling in each column with the water velocity[a] (ft/s) appropriate for the life stage or activity of the species.

Velocity condition	Velocity (ft/s)					
	Spawning	Incubation (eggs)	Larvae	Juveniles	Adults	Other[b]
1. Minimum velocity used.						
2. Maximum velocity used.						
3. Lowest velocity considered to be optimal.[c]						
4. Highest velocity considered to be optimal.[c]						
5. Level velocity must decrease to for SI=0[d] (use N if never occurs)						
6. Level velocity must increase to for SI=0[d] (use N if never occurs).						
7. Velocity level(s) where SI=0.5 (use N if never occurs).						

[a] Generally the mean column velocity (velocity at 0.6 of depth measured from water surface). However, more specific measurements are used sometimes. What do you mean by velocity relative to the values you will give in this table? Underline the following phrase that most closely describes your use of velocity: Velocity at surface of water. Velocity within 6 inches of stream bottom. Velocity at site of fish/activity (e.g., nose velocity). Mean column velocity. Other (please define) ________________.

[b] Specify any other riverine life stage or activity that you consider to be important and fill in column.

[c] SI=1.

[d] Velocity level is totally unsuitable when SI=0.

Appendix F. Table used to elicit opinions of panelists (11) on water depth suitability - Round 1 of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

REDBREAST SUNFISH - DELPHI ROUND 1 - WATER DEPTH

Panelist ______________ Date ________

Complete this table by filling in each column with the water depth[a] (ft) appropriate for the life stage or activity of the species.

	Water depth (ft)					
Depth condition	Spawning	Incubation (eggs)	Larvae	Juveniles	Adults	Other[b]
1. Minimum depth used.						
2. Maximum depth used.						
3. Minimum depth considered optimal.[c]						
4. Maximum depth considered optimal.[c]						
5. Depth water must decrease to for SI=0.[d]						
6. Depth water must increase to for SI=0[d] (use N if never occurs).						
7. Depth(s) where SI=0.5.						

[a] Indicate what you mean by depth in the context of the values you will use in this table by underlining the following phrase that most clearly describes your use of depth: Average water depth. Nose depth or depth at fish/egg/activity. Other (please define) ______________.

[b] Specify any other riverine life stage or activity you consider to be important and fill in column.

[c] SI=1.

[d] Depth is totally unsuitable when SI=0.

Appendix G. Table used to elicit opinions of panelists (11) on water temperature suitability - Round 1 of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

REDBREAST SUNFISH - DELPHI ROUND 1 - WATER TEMPERATURE

Panelist ______________ Date ________

Complete this table by filling in each column with the water temperature (°F) appropriate for the life stage or activity of the species.

Temperature condition	Water condition (°F)					
	Spawning	Incubation (eggs)	Larvae	Juveniles	Adults	Other[a]
1. Minimum temperature used.						
2. Maximum temperature used.						
3. Lowest temperature considered to be optimal.[b]						
4. Highest temperature considered to be optimal.[b]						
5. Temperature water must decrease to for SI=0.[c]						
6. Temperature water must increase to for SI=0.[c]						
7. Temperature(s) where SI=0.5.						

[a] Specify any other riverine life stage or activity that you consider to be important and fill in column.

[b] SI=1.

[c] Temperature is totally unsuitable when SI=0.

Appendix H. Table used to elicit opinions of panelists (11) on water substrate suitability - Round 1 of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

REDBREAST SUNFISH - DELPHI ROUND 1 - WATER SUBSTRATE

Panelist ______________ Date ________

Complete this table by filling in each column with the appropriate SI (0.0-1.0)[a] for the substrate[b] - life stage or activity.

Substrate type		Suitability Index (0.0-1.0)					
Code	Particle size	Spawning	Incubation (eggs)	Larvae	Juveniles	Adults	Other[c]
1.	Organic material						
2.	Mud/soft clay						
3.	Silt, 0.062 mm						
4.	Sand, 0.062-2 mm						
5.	Gravel, 2-64 mm						
6.	Cobble, 64-250 mm						
7.	Boulder, 250-4000 mm						
8.	Bedrock						

[a] Substrate is totally unsuitable when SI=0. If substrate is optimal, SI=1.

[b] Indicate what you mean by substrate in the context of how you will use it for this table. Underline the following phrase that most closely describes your meaning: Dominant substrate particles on surface of substrate. Material comprising highest percentage (by weight) of grab sample. Other (please define) ______________.

[c] Specify other riverine life stage or activity that you consider to be important and fill in column.

Appendix I. Table used to elicit opinions of panelists (11) on suitability of cover[a] types - Round 2 of a four-round Delphi exercise to develop habitat suitability criteria for redbreast sunfish.

Instructions

1. Please consider the suitability indices for cover types listed below.

2. If a cover type named is not important, mark it out or consolidate it with another type.

3. If you disagree with the SI indicated, change the SI to what you feel it should be. Return your results to the Delphi monitor.

Cover type[b]	Suitability indices[b] and life stages or activity			
	Spawning	Larvae	Juvenile	Adult
1. Logs, brush, stumps, snags	1.0	0.2	0.8	1.0
2. Boulders	0.7	0.2	0.5	0.7
3. Gravel-small cobble	0.0	1.0	0.7	0.2
4. Steep banks with over-hanging vegetation and willow roots	1.0	0.7	0.5	0.5
5. Aquatic vegetation (rooted macrophytes)	0.0	1.0	1.0	0.4
6. Plant detritus and/or organic material	0.0	0.4	0.6	0.1
7. Other				

[a]Cover can simply be described as any feature of a stream that provides reduced lighting, reduced velocity, or increased visual isolation. Even more simply, cover is something the fish can either get under or behind. Cover may also provide suitable substrate or habitat for food organisms utilized by the fish.

[b]The cover types and suitability indices resulted from a query made during Round 1 (Appendix D). See Figure 5 and Table 2 for final results on cover suitability.

QUESTION AND ANSWER SESSION

Johnie Crance

Leonard: In this situation, it seems to me that you were a fairly unbiased party in being the moderator of this Delphi technique. I would like to hear what you believe to be the potential bias of the moderator in guiding this process to an end.

Crance: I think it is obvious that the moderator could strongly bias the outcome. You could even be biased about what you think certain people's opinions may be. Bias should be kept to a minimum. The moderator should be objective to the point of disinterest. It is of utmost importance for the moderator to give fair representation of the experts' opinions.

Nelson: Do you have any estimate to how much time it takes to conduct one of these Delphi technique iterations?

Crance: That is primarily up to the panelists and the number of other people involved. It takes each panelist no more than four hours per round. Some people will go into a great dissertation about the results of some research they have been conducting. Others will give their intuitive feelings and it doesn't take an hour for them. The redbreast sunfish Dephi exercise lasted eight months and required about 50 person-hours, for all the people involved (mediator, clerical, and panelists).

Comment from the floor: It seems to me one of the drawbacks to this method is the time it takes for the interchange of information from the experts back to the moderator.

Crance: That certainly is a disadvantage.

Comment from the floor: Have you been looking into the possibility of using electronic mail to speed the process up?

Crance: I haven't looked into it, but I am aware that it is a possibility. I think that you should count on at least six calendar months total time involved and, from my estimate, six months is probably a minimum for one person to be involved in all aspects of a Delphi inquiry.

Brad Caldwell: I think that one of the positive aspects of this is that you leave a very accurate paper trail as to how these curves were established. What do you do, and how much time does it add when you deal with five or six species and four or five life stages per species, with possible interactions or change of habitat?

Crance: It certainly takes more time or more effort. I did one for shortnose and Atlantic sturgeons, simultaneously, and all the panelists, except maybe

one or two, were the same for both species. That's the only experience I have with doing more than one species at a time. I think it would be hard to find one person who is an expert on several species.

Phil Wampler: I may have missed something, but the way the Delphi works, you are looking for an agreement between the experts after a certain number of iterations. Then, you distribute this information between the experts so they can come up with some sort of agreement after a certain number of iterations. What do you do, if after five iterations, you still have considerable disagreement among the participants?

Crance: I set a sort of limit, that after five rounds, I quit, regardless of the results. However, if I reach about 85 percent agreement after three or four rounds, I usually quit then.

Dave Hanson: If you don't reach agreement by the fifth round, what does that mean?

Crance: I don't know what to do about that. It may be a ubiquitous species. I record the disagreements for whatever they are worth.

Hanson: You're not making a judgment based on everyone's opinions are you?

Crance: No. I record the disagreement as well as those experts that agreed.

Hanson: How many cases have you been involved with using this technique?

Crance: Seven species.

Hanson: Did they all come to an agreement?

Crance: Yes, generally there has been about seventy percent total agreement. In the remainder, there have been very minor disagreements.

Corning: Is this disagreement on just certain portions of the curves or is it on the whole curve?

Crance: Most of the disagreements are focused on portions of the curves.

Barrett: Have you compared the redbreast sunfish curves developed by the Delphi method with empirically based curves developed from fish observations.

Crance: I have not, but with the information Paul Leonard gave yesterday on Virginia streams, there may be enough information to make such a comparison. I don't know if that is available yet or not. It would be interesting to compare them.

Leonard: Don Orth was one of the panelists for the redbreast sunfish Delphi and apparently he had some disagreements with some of the curves.

Crance: One of his disagreements was on velocity. He seemed to think that zero velocity was okay for spawning for redbreast sunfish whereas the other panelists felt that you should have some velocity.

Leonard: You have alluded to some differences in some of the variables across the geographic range of the species. Did you see trends of north and south in responses of the experts? Did you stratify them by region?

Crance: I did see differences, but I did not try to stratify them. I did record the information that was provided to me. The greatest differences appeared to be in the temperature curves. We are not talking about a big range there either. Two or three degrees or less.

Lifton: The application of this technique to other fields appears to be an exciting possibility. What they have observed in other applications is that the experts wouldn't reach consensus in the first couple rounds. Where consensus could not be reached, the criterion used to determine if they had reached a stopping point was if the responses were stable over a certain number of rounds.

Crance: Well that occurs, but it became obvious in the first round that what everybody believed was based on their experiences, as well as information that was available. The responses tended to evolve, which I tried to show in Table 3. There was a reaching of the consensus, however, but it didn't occur until the fourth or fifth round.

Sheppard: One of our experiences with American shad using a Delphi-type technique was entirely oriented towards large rivers. Here, the experts overlooked the fact that shad will spawn in shallow waters, depending upon the riverine situation.

Crance: I'm not sure that I understand what the difference between a large river and a small river means when it comes to shad spawning. Do shad spawn in large rivers and small rivers?

Sheppard: All the experts were experienced in large rivers, and they developed curves on that basis. None of these experts had ever had any experience with shad spawning in shallower water.

Crance: People's reactions to the preliminary curves that I developed changed dramatically. People would introduce data, or rationale based on data plus experience, and other respondents would react to that.

THE USE OF RISK ANALYSIS TO ESTABLISH ERROR BOUNDS FOR CATEGORY I CRITERIA

by

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Several authors in this session have discussed the merits and liabilities associated with criteria that have been developed by professional judgment. Despite any philosophical problems one might have in using criteria based on intuition rather than on data, the fact remains that category I criteria will be used in instream flow studies for the foreseeable future. It is noteworthy that biology is not the only profession in which decisions must be made in the face of uncertainty. Such problems are also encountered in such diverse fields as oil exploration, marketing, medicine, and strategic defense. Planners and decisionmakers in these fields often turn to "decision theory" or "risk analysis" to make reasonable and logical analyses of problems in uncertain environments.

Baldridge (1981) has demonstrated that it is possible for knowledgeable experts to develop accurate category I criteria. The key factor for obtaining accuracy, however, is the experience base of the professionals on whose opinions the criteria are formulated. Where the experts are very knowledgeable about the behavior of an animal, the criteria will probably be accurate, and there will likely be a high degree of consensus and confidence in them. However, when even the experts do not know very much about the behavior or requirements of an organism, there may be a lack of consensus and a great deal of uncertainty related to the accuracy of the criteria. This type of problem is typical of studies involving endangered species.

Category I criteria are somewhat unique in the amount of uncertainty they may embody. First, the objective function itself (i.e., the suitability curve) may be highly subjective. Second, the amount of error associated with the function is often unknown, even to the people who developed it. When curves are fit to empirical data, it is at least possible to obtain some measure of the goodness of fit, such as a residual sum of squares. Although many of the errors associated with category II or category III criteria may be well disguised, imprecision in the measurement techniques may result in a large amount of scatter in the data. This, in turn, usually results in some test statistic reflecting the error. To a practitioner contemplating the use of a set of criteria in an instream flow study, some knowledge about the

reliability of the criteria is essential. This information is usually lacking for most category I criteria, so the user may conservatively assume that the criteria are inherently inaccurate. This may be an acceptable alternative where there are plenty of criteria sets to select from, but not where the only criteria available are category I. Adaptation of some of the concepts of decision theory allows criteria developers to evaluate the potential error associated with the curves they develop.

Decision theory is derived from Bayesian statistics, which is viewed by some as more of a philosophy than a true statistical discipline. The underlying concept of decision theory is that empirical probabilities based on relative frequencies can be (a true Bayesian would say "should be") conditioned by intuitive judgements. These are termed "subjective probabilities." A subjective probability reflects the degree to which a person believes a proposition to be true. Thus, the "posterior probability" is the product of both the empirical probability and the subjective probability that the empirical case is correct (Walpole and Meyers 1972). A complete discussion on decision theory anaylsis is given by Raiffa (1968).

METHODS AND PROCEDURES

The typical product of a successful category I exercise is a set of suitability curves or binary functions. This type of function may be developed through roundtable discussions, Delphi exercises, or onsite habitat recognition techniques (Bovee 1986). Error bounds around the suitability function can be established in much the same way that the original function was developed. In this case, each point on the curve is evaluated by members of the criteria development team. A Delphi questionnaire is used to determine the collective degree of confidence in the curve, according to the people who developed it. For example, assume that the smallest suitable depth is given as 30 cm. Respondents are asked to assign subjective probabilities to increasingly larger increments around this point. For example:

"The smallest suitable depth is estimated to be 30 cm.
What is the probability that the true value lies between 25 and 35 cm?
What is the probability that the true value lies between 20 and 40 cm?
What is the probability that the true value lies between 15 and 45 cm?"

The respondents then give their estimates of these probabilities for each of the increments, and the process is repeated for every point on the curve. For most category I curves, this usually amounts to three or four points.

After the curve developers have given their subjective probabilities for all of the increments, a project leader or monitor team must then compile the responses. One of the easiest aggregating techniques is simply to compute the arithmetic average of the subjective probabilities for each increment. When this approach is taken, the standard deviation and coefficient of variation should also be determined. A large coefficient of variation (e.g., >50%), indicates that there is considerable disagreement regarding the potential error. It does not necessarily mean that the potential error is large. If all the respondents are satisfied that 30 cm is indeed the smallest suitable

depth, then there should be agreement that there is a high probability that the true value lies between 25 and 35 cm. Curiously, a large amount of uncertainty can also result in a small coefficient of variation. Everyone might agree that there is only a 50% chance that the true value falls between 15 and 45 cm, for example. What this tells the project leader is that all of the respondents agree that they are not very confident in the curve they developed.

Another aggregation technique is to array the subjective probabilities in an exceedance distribution. In this case, the monitor team would identify the median and interquartile (25% and 75%) responses. The ratio between the 25% and 75% exceedance values can be used as an index of the variation in responses, similar to the use of the coefficient of variation. Although there are no firm guidelines for the range of responses that indicate agreement or disagreement, it should be apparent that the closer the ratio to unity, the better the agreement. A large disagreement, as suggested by either index, may dictate subsequent rounds of Delphi inquiries in an attempt to achieve a consensus. The reader is referred to Linstone and Turoff (1975) for guidelines in conducting multiround Delphi exercises.

Having determined the subjective probabilities for each of the increments surrounding all of the points of a suitability curve, a line can be drawn connecting increments having equal probability estimates. It may be necessary, in some cases, to interpolate between probability estimates to draw these isolines. The area between the lines represents the "subjective confidence interval" around the suitability curve. This should not be confused with statistically derived confidence limits. The interval does, however, give users a good idea of how confident the curve developers are in the accuracy of the curve.

DISCUSSION

The development of subjective confidence intervals seems to be a straightforward and simple process, with a large benefit to potential users; however, there are some problems to consider.

One of the obvious advantages of this approach is that it allows criteria developers to evaluate their own level of knowledge. As a corallary, it also provides the user with a quasi-quantitative index of the reliability of the criteria. (Note, however, that the user must still address the issue of transferability as an independent evaluation). Another benefit of this approach is that it allows the incorporation of more information in the curve. A user might choose to conduct a sensitivity analysis, using the inner and outer confidence intervals, to determine the extent to which PHABSIM results would change, depending on the curve set used. If the change is minimal, then the curves can be used with little or no further evaluation. A field verification study is suggested if the PHABSIM results are sensitive to potential errors in the curves.

A common problem with category I criteria is that it is often difficult to incorporate minority opinions. This is especially true where criteria are developed by roundtable discussions. Even the most altruistic criteria

development exercise can be weakened by the bandwagon effect, the influence of a dominating personality, or a tendency to develop criteria by popular vote. All of these factors tend to discount viewpoints held by a minority of the participants. By conducting a "risk-analysis" exercise, particularly by the Delpi technique, it is possible to introduce the concerns of the minority into the final product. (The use of the arithmetic mean aggregating approach gives more weight to minority opinions than does the exceedance approach, something that should be kept in mind by the monitor team.)

The most serious problem encountered in the development of the subjective confidence interval is related to the types of scales used to describe independent variables for habitat suitability curves. The example used in this discussion is easy to derive because depth is a continuous variable, on an integer scale. Thus, symmetrical increments about a single point on the scale (e.g., 30 cm) are real numbers and have real meaning. The same is true for velocity. Substrate, however, may be a continuous variable based on particle size, but it is usually expressed on an ordinal scale. That is, the numbers on the scale are not real, but are used to express a class of particle sizes. Establishing symmetrical increments around a substrate code of 5 would be meaningless, primarily because the particle size classes for each code are based on a geometric classification system. Suppose, for example, that a substrate code of 5 represents gravel, and codes of 4 and 6 represent sand and cobbles, respectively. When questioning the accuracy of a trout spawning curve that peaked at substrate code 5, it is likely that all respondents would say that there is a very high probability that the true value lies between 4 and 6. This might be a satisfying response for the model builders, but not very useful for a potential user of the information.

The problems associated with cover codes are even more intractable because cover is a discrete variable, expressed on a nominal scale. Whereas increasing substrate codes imply increasing size classes, cover codes are nothing more than numbers that represent the name of a cover type. The order in which the numbers appear are meaningless to the sequence. Adjacent code values have absolutely no mathematical relationship; it is impossible to interpolate a cover type between an undercut bank and a boulder, for example. Thus, attempting to define intervals around cover codes borders on the ridiculous.

There are ways to solve the substrate and cover code problems. In the case of the substrate coding system, it is possible to convert the ordinal scale back to an integer scale by recording actual particle sizes rather than codes. This is a practical alternative for all substrates that are delinated by a size dimension. It is not a solution for substrates such as submerged aquatic vegetation or bedrock. Where the substrate <u>can</u> be converted to an integer scale, the imposition of confidence intervals serves to redefine the size classes to be included in a code classification. Rather than stating that the minimum size class of substrate that can be used for spawning is code 5, the question would be stated as:

> "The minimum size of usable gravel is given as 16 mm. What is the probability that the true minimum lies between 12 and 20 mm?

Presumably, this is more informative to the user than the absolute certainty that trout spawn on gravel.

The most plausible solution to the problem of cover codes may be to establish confidence intervals around the suitability index rather than the code value. In this case, the query would be phrased as:

> "The assigned suitability for instream overhead cover is 0.5. What is the probability that the true values lies between SI values of 0.4 and 0.6?"

This is an imperfect solution because the SI scale is confined to values between 0.0 and 1.0, and it is not possible to bracket these two values. Consequently, the lowest possible confidence interval is zero and the highest, unity. Despite this deficiency, placing confidence intervals around intermediate suitability values has merit, and even for suitabilities of zero or one, half a confidence interval is better than none.

This discussion has illustrated the use of symmetrical intervals around each point on a curve. There is no reason that these must be symmetrical, and the argument could be made that they should not be. Developing asymmetrical intervals would require more work, but would follow the same basic procedures as described previously. The difference is in how the Delphi question is phrased. Instead of asking whether the true value lies between 20 and 40 cm, for example, the question should be split up:

> What is the probability that the true value is greater than 20 cm?"
>
> and
>
> "What is the probability that the true value is less than 40 cm?

This form of inquiry may result in symmetrical confidence intervals, but this result is not guaranteed from the outset, as it is in the previous example.

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QUESTION AND ANSWER SESSION

Ken Bovee

Jean Caldwell: Are you going to try this (using confidence intervals on professional judgement--eds.)?

Bovee: If I were involved in a case using category I criteria, that was going to court, I would try it because I think it might resolve some of the problems you (Caldwell and Hilgert) talked about yesterday. For example, if I were asked under a cross-examination, "How do you know these curves are any good? How do you know they're right? I could answer, "I don't know, but the experts said this is what it looked like." Then the question comes back, "Well, how confident are the experts that they know what they are talking about?" Of course this could backfire on me. I could have confidence intervals the size of Texas, but if that were the case, we would try to refine the curves before spending a lot of time on analysis.

Smith: If I understand the technique you described correctly, what you are saying is that the experts agree, not necessarily that the experts are correct.

Bovee: The method does not imply that the experts are correct, that's true. What it provides is a measure of the degree of the belief by the experts that they are correct. This gets back to Baldridge's study. The reason that those criteria came out so close to subsequent verifications is because those biologists have been measuring salmon habitat for years. Similarly, if we compare the Delphi curves that Johnie (Crance) put together with the data that Don Orth and Paul Leonard collected on the redbreast sunfish, they're going to be very, very close. Don was one of the participants on the Delphi panel and he will likely base his experience on the data that they collected. There is that kind of a feedback loop in there.

Kinzie: Some people have found that in doing what you suggested, some of the respondents are going to be extremely conservative in their estimates whereas others are going to be gamblers, if you will. What they've suggested is to imbed certain kinds of questions within the questionnaire to determine whether a respondent is a gambler or a conservative-type respondent.

Bovee: That is a really good idea, but that kind of question really has to be kind of camouflaged so the respondents don't catch on to what you're up to. Another form of questioning can be directed at a self-evaluation of one's own expertise. I have been a party to some of these inquiries where I was asked to respond to questions that I was totally unqualified to answer. So, there is a range of knowledge by the participants within one of these exercises. I think what you might want to do is (a) evaluate for the gamblers and non-gamblers, and (b) have people put down probabilities only for those things they are qualified to say anything about.

ACQUISITION OF HABITAT PREFERENCE DATA BY RADIOTELEMETRY

by

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INTRODUCTION

Underwater radiotelemetry is a relatively new and rapidly developing methodology for monitoring fish behavior in the natural environment. Its use is particularly recommended in riverine and other systems where some types of biotelemetry may be unsuitable (Stasko and Pincock 1977). Beginning in the late 1960's (Winter 1983), radiotransmitters were designed for underwater application, and many fish species were monitored in the 1970's with externally and internally attached radios (reviewed by Tyus 1982 and Winter 1983). Radiotelemetry has been used primarily for fish movement studies but has seldom been used for microhabitat determinations. However, fish radiotelemetry offers great promise for microhabitat studies, especially with the use of surgically implanted internal transmitters (Chamberlain 1979), which avoid the abnormal behavior previously observed in some telemetered fishes using external transmitters (Ross and McCormick 1981; Mellas and Haynes 1985).

Fish radiotelemetry is most difficult for migratory species and adverse riverine environments, e.g., high conductivities, changing temperatures, and variable flow regimens (Tyus 1982). Radiotelemetry may be the least biased method for obtaining habitat utilization data in such environments, however, since gear selectivity is avoided and the same fish can be monitored for long periods of time. Few investigators have evaluated relative radiotracking success, and no standard criterion is used for comparing radiotracking efforts between investigations. A method of success evaluation under different environmental conditions or for different tracking methods would aid others in the selection of gear, and provide insight into manpower needs.

This paper is divided into two main parts: part one provides a theoretical background in fish radiotelemetry; part two uses a case study to evaluate radiotracking success, to relate habitat utilization data obtained from radio-tracking to the Instream Flow Incremental Methodology (Bovee 1986), and to discuss data partitioning. The radiotelemetry of the migratory Colorado squawfish (Tyus 1985) in the Green River of Utah provides an example of a large predator that is difficult to radiotrack because it lives in a large

river that has high water conductivities, and turbidity precludes visual observation.

RADIOTELEMETRY BACKGROUND AND THEORY

The use of radiotelemetry for obtaining physical microhabitat utilization data on fishes is in its infancy (Tyus et al. 1984), and little guidance can be obtained from published sources. Bovee (1986) summarized most of the available information about radiotelemetry for the development of habitat suitability criteria of stream fishes. This paper expands an earlier paper (Tyus 1982) providing background information on radiotelemetry, updating methods, and simplifying theory.

Radiotelemetry has been used to monitor movements and behavior of terrestrial animals for many years. Earlier workers did not use radiotelemetry for studying fish movement because it was believed that radiotransmission through water would be too poor to be effective; they relied primarily on ultrasonics (Stasko and Pincock 1977). There are, however, several disadvantages of ultrasonic tracking. For example, the detection of ultrasonic signals requires that the receiving hydrophone be immersed in water. This makes tracking difficult with ice cover and also eliminates the use of aircraft. Ultrasonic telemetry is markedly influenced by water temperature, turbulence, and sediment load. Temperature affects the velocity of ultrasonic emissions, and, in deeper waters, a thermal discontinuity may reflect ultrasonic energy away from the hydrophone. Entrained air from waves, boat propellers, and the movement of bottom sediments caused by stream currents may cause enough noise to mask ultrasonic reception. For these reasons, radiotelemetry has been the method most recently used for monitoring fish in large river systems where visual observation is precluded by turbidity and conductivities are moderate (Winters 1983).

Radiotelemetry uses a battery-powered radiotransmitter to generate radio waves (electromagnetic radiation), which are propagated through the water. This transmitted energy must then cross the air-water interface and be received by an antenna operating in air. The propagation of radio waves through any medium, in this case water, is inversely proportional to the frequency. Thus, radio waves of high frequency travel a given distance with a greater loss of power than an emission of lower frequency. The nature of the change in propagation with frequency is approximately logarithmic (Lonsdale 1967; Lonsdale and Baxter 1968). Radio signals are attenuated (diluted) more rapidly in water than air, and the amount of attenuation is inversely proportional to the conductivity of the water (Weeks et al. 1977). For this reason, a considerable loss of signal strength is expected when radio waves are propagated through fresh water of high conductivity. Radio transmission in salt water is virtually impossible.

The behavior of radio energy at the air-water interface (Figure 1) is an important consideration for radiotelemetry. Energy contacting the interface is reflected unless the angle of incidence is less than 6° (Weeks et al. 1977). Radiation of the energy that passes this interface produces a signal,

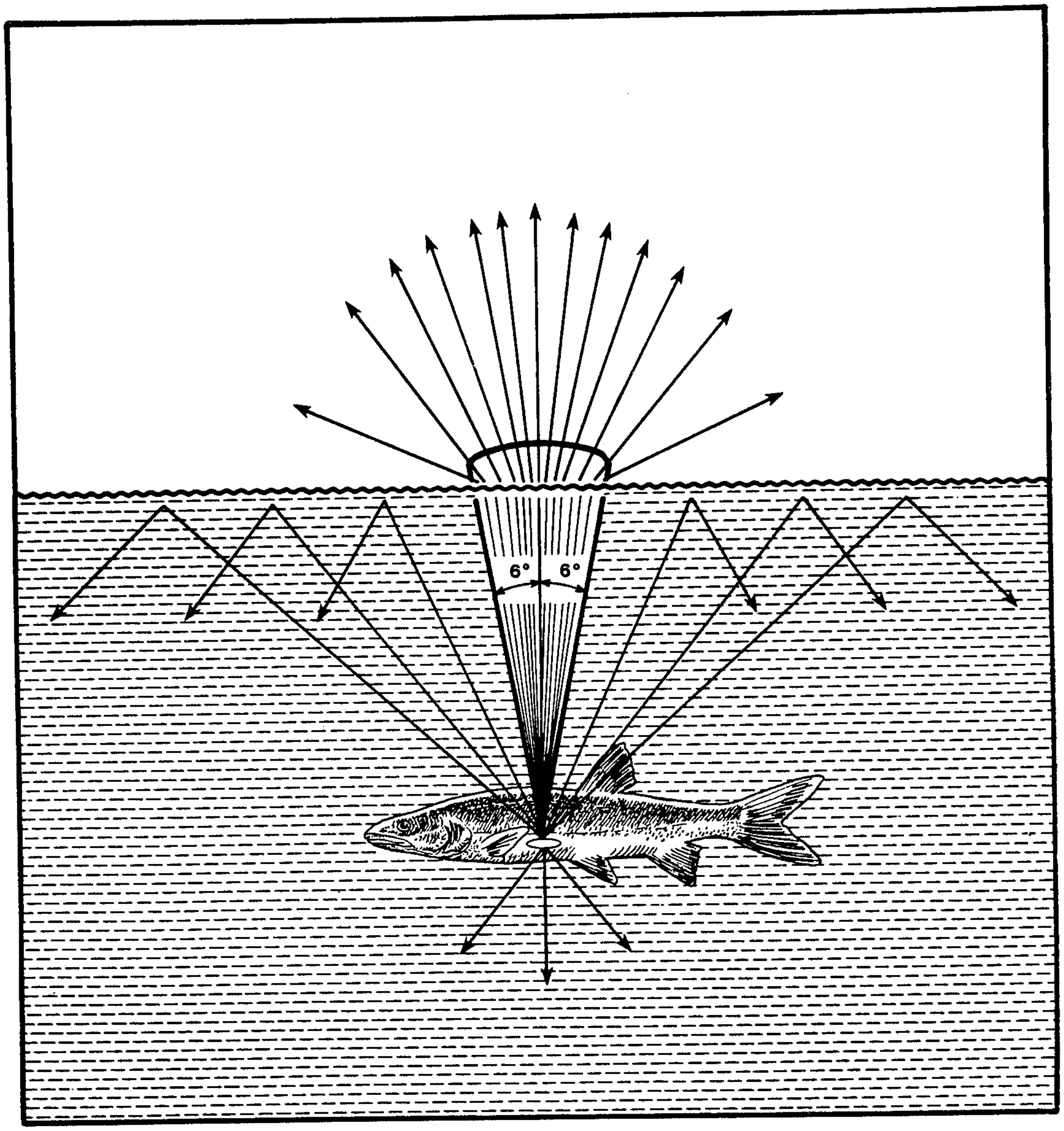

Figure 1. Radio signals from a transmitter, passing through the air-water interface.

with the apparent signal source being a circle on the surface of the water (Priede 1980). The size of the signal source could be calculated by trigonometry, but is obviously small, particularly in shallow water. It is this small circle that is located by radiotrackers and provides the location for taking habitat measurements. As indicated in Figure 1, only a small portion of this radiated power actually crosses the air-water interface and is available to the receiving system. However, if any "significant" energy breaks through the interface, radio reception can occur at long ranges because of the rapid propagation of radio waves in air (Stasko and Pincock 1977).

Radiotelemetry in high conductivity waters of 400 µmho or more is marginal (Sinning 1979; Winters 1983), and efforts must be taken to maximize the

reception of the radio signal in the field. Unfortunately, workers are constrained by equipment to only a few options. Any increase in received field signal strength from transmitter to a receiving radio is dependent on power output, efficiency of transmitting and receiving antennas, and the sensitivity of the receiving system. The other factors affecting reception are principally environmental and will be discussed in the case study.

The type and size of battery used with radiotransmitters is an important consideration from the standpoint of size, weight, range, and life. For a given application, battery weight and size is directly proportional to range (power output) and the transmission life. Fish transmitters can be designed to operate for hours to years with a given battery, but the range (signal strength) decreases as transmitter life increases. Although range can be increased by using a larger battery, the weight and size increase may not be acceptable. If the theoretical longevity of a battery is obtained by dividing the current demand (drain) of the transmitter (milliamps) into the battery rated capacity (milliamp days), the resultant rating (life) of a radio module (transmitter, antenna, and battery) provides a useful guide for module selection.

Battery life is also dependent on pulse duration and pulse rate of a transmitter, since these represent power output. The threshold sensitivity of the human ear indicates that a reduction of a pulsed tone not be reduced less than about 30 ms (Kolz and Johnson 1981), and tracking is more difficult at pulse rates less than about 30 per minute. Most investigators use a chronograph (stopwatch) for determining pulse rates of transmitters; this method is simple and the gear dependable for field use. Although sophisticated "pulse interval timers" are available from industry, their high technology and potential oversophistication may offer no advantage at higher cost.

Only a few types of transmitting antennas are suitable for monitoring fish. The two main types are straight whip and tuned loop. Whip antennas are generally small and omnidirectional. Although a whip antenna can be compressed in length by shortening it from 0.5 to 0.25 wavelength, or by coiling part of it, a loss in efficiency occurs. A decrease of the diameter of an antenna also reduces efficiency. The required length of the whip antenna is dependent on the wavelength, and reducing the wavelength by raising the frequency will allow greater efficiency for a given antenna size. Unfortunately, a frequency increase lessens radio wave propagation through water; thus, the gain in efficiency of antenna operation is less at higher frequencies. Use of a loop (coiled) transmitting antenna or incorporation of the implant capsule as part of a dipole antenna have proven desirable for surgically implanted modules because of the necessity for compactness and the need to avoid protruding antennas. It may be possible to increase the radiation resistance (antenna efficiency) of some types of coiled antennas by increasing the length of the coil. However, for a "tuned" inductor type or other sophisticated antenna designs, the antenna may be part of a circuit, resonating at a certain mode. The tuned inductor types of antennas, therefore, may not be made more efficient simply by increasing their lengths.

Transmitting antennas must radiate radio signals in all directions. Receiving antennas should have a capability for receiving from all directions

as well as functioning directionally. The only practical approach to this problem with existing technology is to employ two separate antennas. For fish work, the omnidirectional straight (or whip) antenna can be used to receive signals from all directions. For directional tracking, either a loop or Yagi antenna may be used. The loop antenna resembles a hoop on a stick. The Yagi type consists of several short cross pieces mounted perpendicular on a vertical pole (Figure 2).

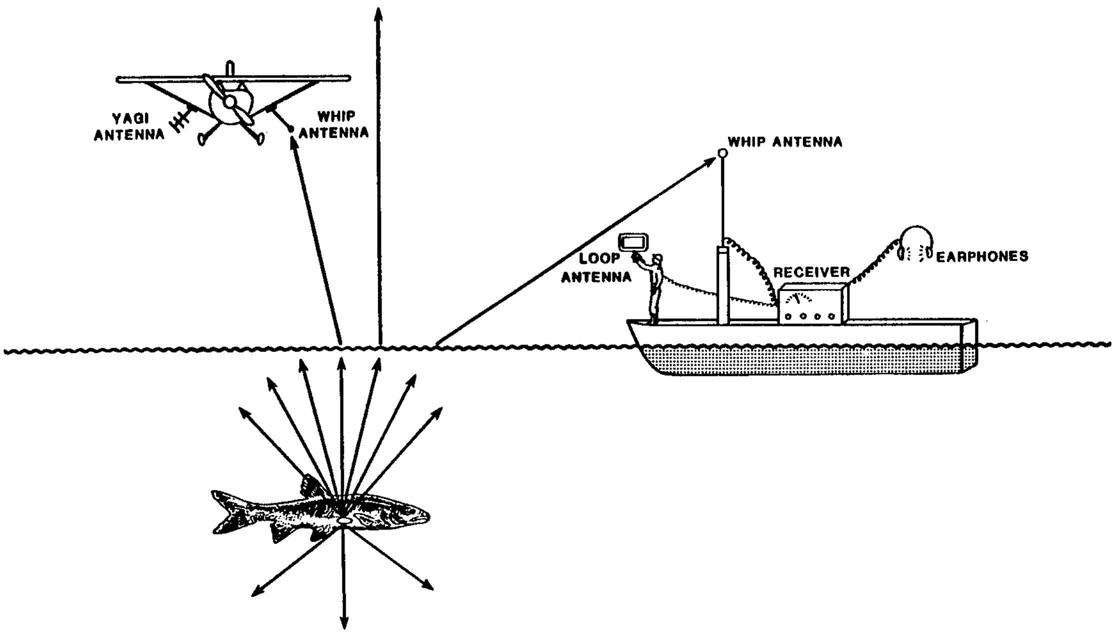

Figure 2. Radio signals from an implanted fish to receiving systems illustrating different types of antennas.

A 0.25 wavelength simple whip antenna is about 1.5 m long (at 50 MHz). The whip antenna usually rests on some object on the ground plane. A ground reference plane placed perpendicular to the whip antenna aids in efficiency (Tyus 1982) especially if the antenna is mounted on a high stand. The whip antenna is more sensitive than a loop of comparable size, but less sensitive than a Yagi. Its advantages are simplicity of design, low cost, and ease of mounting. This antenna has the least air resistance and, for this reason, is preferred for aircraft use. The convenience of a whip antenna makes it more desirable than a Yagi for fish work, and the loss in efficiency is slight. Unlike terrestrial applications, directional antennas are not necessary for aircraft tracking in rivers for two reasons: (1) rivers provide their own boundaries, and (2) all microhabitat studies require follow-up by boat when habitat data are recorded from more precise fish locations.

Once a fish has been located (Figure 2) by an omnidirectional whip antenna, loop and Yagi antennas are used to locate the signal source by rotating the antenna until the null (or minimum) reading for signal strength is detected. For the Yagi antenna, the gain (efficiency) increases with an increasing number of elements in the antenna, although the rate of increase becomes less with each element added. Each element of the 0.5 wavelength

antenna is approximately 3 m long at 50 MHz. These elements are mounted on a boom that ranges in length from about 1.5 m for a 2-element Yagi antenna to nearly 4 m for a 5-element Yagi antenna at 50 MHz. The antenna should be at least 0.5 wavelength from the nearest large object in order to be highly directional and effective in radio signals (gain). A 50 MHz antenna must be mounted at least 3 m above the ground because ground reference may interfere with performance. Yagi antennas are most effective when used from a fixed location because of the constraints discussed above and the large size of the antenna. The loop antenna does not have as much gain or directivity as a Yagi antenna, but it is adequate for close work once a fish has been located. Loop antennas are recommended for fish work because they can be made small, and they are more rugged and less sensitive to interference from objects in their proximity than Yagis. Loop and Yagi antennas are bidirectional and require readings from two different locations so that triangulation can be used to locate the signal source. A simple bidirectional loop antenna for 50 MHz is about ½ m in diameter. Smaller diameters can be used, but some loss of sensitivity is to be expected.

After the antenna has received the radio signal, the signal is relayed through coaxial cable to the receiver where it is converted to an audio or visual signal. Coaxial cables have unavoidable efficiency losses due to their construction. These losses can be minimized by the proper choice of cable, keeping cable lengths short, and frequent inspection to make sure the cable is not flattened or nicked. Connectors also cause a loss of efficiency. Some investigators have used coaxial splitters to separate the signal from one coaxial cable to two cables. This method allows one antenna to be shared by both a search and a pinpointing type receiver. Since this can result in a loss of received signal strength, it should be avoided. Better techniques are to use two trackers or to split the earphones to receive both signals simultaneously (a different signal for each ear). Other investigators have used signal strength boosters between the antenna and receiver. However, care must be taken so that the noise level is not boosted so much that it interferes with signal reception. Listening to increasing amounts of static does not improve tracking!

Losses associated with the transfer of signals between the antenna and the receiver are usually small, but they can significantly affect field results. For example, water, dirt, or corrosion on the conductors can diminish the signal strength. These effects must be recognized and avoided by careful upkeep of equipment, especially in high conductivity waters where signal propagation is suboptimal.

The radio signal is converted in the receiver to an audio, visual, or other type of display useful to monitoring personnel. Receiver design involves many considerations and currently approaches theoretical limits for factors such as sensitivity (primarily limited by thermoelectric noise generated within the receiver) and selectivity (ability to differentiate the desired signal from other signals).

There are three principal types of receivers: (1) the "search" (or scan) receiver, which will simultaneously pick up signals from any transmitter in use; (2) the "tracking" (or pinpointing) receiver, which is used to locate and identify individual transmitters; and (3) the "programmable" receiver, which

can be programmed to recognize frequencies and usually rotates through a number of programmed frequencies at a certain rate. Any major field study should use receivers with search and track capabilities, especially if several transmitters are used. A search model is greatly desired for fish tracking; it can prevent loss of a fish if temperature changes or other factors cause a transmitter to emit a slightly different frequency. The search receiver, however, cannot be tuned as precisely for individual transmitters as a pinpoint receiver and cannot have as great a range in terms of signal strength received or distance. Because radiotelemetry was developed principally for wildlife applications, many tracking receivers are not tunable except for 10 or more narrow frequency bands. These should be avoided in fish tracking work in favor of "search" and tunable "tracking" receiver types. Programmable receivers require the exact frequency of the transmitter to be input as a known. If temperature changes cause the frequency to change very much (as is often the case with small transmitters implanted in cold-blooded animals), the receiver may not be able to detect the signal. Also, if the unit requires much time to rotate through the frequencies one at a time, a fish location could be overflown in aerial tracking.

CASE STUDY: RADIOTELEMETRY OF COLORADO SQUAWFISH

In March 1980, the U.S. Fish and Wildlife Service initiated a radiotelemetry study of endangered fishes in the Green River as part of the Colorado River Fisheries Project (Tyus and McAda 1984). The study area included the Green River from Jensen, Utah, to its confluence with the Colorado River, about 500 km downstream. Within this area, the river flows through long stretches of flat water, enters whitewater in Desolation and Gray Canyons, and passes through another flat water reach on its way to join the Colorado River. The river has a relatively high conductivity (ranging from about 200 to 2,000 µmho) and is full of underwater objects and obstructions. The river is shallow (<10 ft) through most of the study area.

This case study evaluates radiotracking success in a large river, compares habitat data based on radiotagged fish with data collected by electrofishing, and discusses habitat data partitioning. The potential effects on the fish of surgically implanted radios is evaluated by a comparison of growth rates between implanted and nonimplanted fish.

METHODS

"Antenna-less" (transmitting antenna sealed within a coated capsule) radio modules (AVM 1979) were obtained from the AVM and Smith-Root companies. These radios consisted of a transmitting antenna, radiotransmitter, and battery, all sealed in a water-tight capsule. Each had a magnetic switch and was activated when implanted. Short-life and long-life radios were evaluated from each company:

AVM 180 d and 1½-year modules with "Sm 1" fish transmitters and loop antenna, and powered by 3 types of mercury batteries (630, Hg 1, and 828). These were coated with acrylic resin.

Smith-Root 150- and 300-day modules with "P 40" fish transmitters with a modified dipole antenna, powered by one type lithium battery in series (B body) and parallel (C body). These were encased in a polycarbamate body.

All radios were grouped by the general battery rating provided by the companies. Theoretical transmitting life within each group was calculated for radio type by dividing the average current drain of the transmitters in milliamps by the average milliamp-day rated capacity of the battery used (Table 1).

Table 1. Specifications of radiotransmitter modules implanted in Colorado squawfish.

Type	Company	Type battery	Rated life (d)	Weight (g)		Length (cm)
				In air	In water	
A	Smith-Root	Lithium	150	15	4	5
B	Smith-Root	Lithium	300	22	5	8
C	AVM	Mercury	180	11	3.5	5
D	AVM	Mercury	550	23	6	9

Colorado squawfish were captured and surgically implanted in April and early May (Bidgood 1980; Tyus and McAda 1984). Fish modules were tested for transmitter frequency and pulse rates and dipped twice in melted, purified beeswax before intraperitoneal implantation. All surgery was performed by the author or under his supervision so that the surgical technique did not vary between fish. Care was taken to insure that internal organs were not inadvertently cut during the surgery. In 1980, fish were held about 5 days before release, to test surgical procedure, fish recovery, and suture retention. From 1981 to 1985, all fish were released immediately after implantation. Nine razorback suckers were implanted with three types of radios and released during this time period, but because of low numbers they were not used for comparisons of radio performance.

Fish were tracked weekly with Smith-Root Model RF-40 and SR-40 receivers tuned to the 40.600-40.700 MHz range. Fish were detected primarily with Larsen-Kulrod whip antennas, but Yagi and loop antennas were also tested. Receivers were tested each day. A difference in auditory quality was evident between the radio transmitters, but all were judged acceptable. Signal attenuation with increasing water depth and conductivity (Tyus 1982; Winters 1983) was noted. Tracking was usually done with two boats traveling slowly downstream on opposite sides of the river, although some tracking was done

with fixed-wing aircraft. Water conductivities and temperatures during tracking operations were obtained from the U.S. Geological Service for the Jensen, Utah, gaging station.

Habitat preference information was obtained from monitoring locations of Colorado squawfish in the field and measuring habitat parameters at these sites (Tyus et al. 1984). The initial contact site was recorded and diel studies were made in 1980 and 1981, using the following sampling design. Fish were selected by tag number using a table of random digits. The day was divided into three 8-hour periods, and one period was picked at random. Beginning with the selected 8-hour period, each fish was observed in turn, for three 8-hour periods, and its location was recorded every 15 minutes. After the fish had been observed for three 8-hour periods, the fish with the next tag number was observed. Habitat data were also collected during daylight hours from 1980-85, but these data were recorded from single daily contacts. When a fish signal was detected by search receiver (SR) and whip antenna, its approximate frequency was tuned by the tracking receiver (RF) using another whip antenna. At this point, further monitoring was accomplished on the nearest river bank using the RF and loop antenna. At least two lines of sight were transected through the signal source to form two legs of a triangle. These lines were made reference transections by using two stakes driven into the shoreline about 10 m distant. These stakes were aligned with the signal source to furnish a convenient sighting reference. The lines of sight established by the stakes were then checked frequently to make sure the fish location was the same.

If a radiotelemetered fish remained in one location for 30 minutes, it was assumed that this was preferred habitat. At that time, microhabitat information was recorded by wading or by boat. In determining the exact location of the fish, the observer lined up the stakes previously driven into the shoreline, to arrive at the apex of the resulting triangle. Habitat data taken at the signal source included general habitat and substrate type, water depth, and velocity. General habitat types included:

Shorelines = shallow, low-velocity waters next to shore
Eddies = deep shoreline whirlpools with upstream velocity
Runs = channels with swift laminar flow
Backwaters = semi-isolated water bodies with no measurable velocity
Pools = deep, quiet portions of the stream

Water depth, velocity, and substrate measurements were taken only when the fish moved to another location or at the end of the study period, to minimize disturbance to the fish. Water depth was recorded by direct measurement with a wading rod, and water velocity was measured 0.6 the distance below the water surface with a Marsh-McBirney current meter. Substrate type was obtained by direct observation and by probing with a wading rod. Beginning in 1984, additional readings were taken 2 m inshore (shallow) and 2 m offshore (deeper) of the fish location.

Data obtained from fish captured by electrofishing during 1980-81 were used in comparisons with the 1980-81 radiotelemetry data. An attempt was made to reduce bias in fish collections by using a standardized sampling program, and rivers studied were divided into eight relatively homogeneous sections of

fish habitat based on general river geomorphology (Tyus et al. 1984). Habitats within these stations were sampled using electrofishing, trammel nets, seines, and wire traps, depending on the suitability of each gear type, but only electrofishing data were used for comparisons. The habitat and substrate types at the point of capture for each Colorado squawfish were recorded, and water depth and velocity were measured as previously described.

Growth rates of implanted Colorado squawfish and razorback suckers from which radios were removed were compared to nonimplanted fish of the same size, by obtaining fish lengths from capture-recapture records. Only fish recaptured from the Green River Basin whose lengths fell within the size range of the implanted fish were used for this comparison.

RESULTS AND DISCUSSION

Radiotracking Evaluation

A total of 92 Colorado squawfish were captured and implanted with one of the four radio modules evaluated during the study period. There was no significant difference (Student's t, $P < 0.01$) in the average battery life obtained by tracking mercury and lithium modules under field conditions (47% and 47.5% of theoretical) but there was a wide range between the four radio types: from 34% to 60%. Radios were small with respect to the sizes of the fish used; they were less than 1% of the average fish body weight and about 10% of the average fish length (Table 2).

Table 2. Type, longevity (duration of field contact), and size of radios implanted in Colorado squawfish and tracked in the Green River 1980-1985. n = sample size. Type A and B = Smith-Root modules, Type C and D = AVM modules.

Type	n	Rated life (d)	Longevity: Average (d)	Longevity: Range (d)	Average observed/ rated life (%)	Transmitter size: % fish weight	Transmitter size: % fish length	Average fish TL (mm)
A	25	150	90	57-167	60	0.5	7.3	687
B	9	300	102	71-167	34	0.9	12.1	660
C	43	180	86	0-157	48	0.8	9.0	557
D	15	550[a]	260	93-543	47	1.1	14.0	642
				AVERAGE	47.3	0.8	9.7	625

[a]Listed as 1½ year by manufacturer.

One radio type was monitored for over one year. Mercury-powered modules rated for 1½ years of life averaged 260 days, and five (33%) functioned for over one year (455 to 542 days). In spring 1985, a fish was recaptured (after 12 months) with a defective radio. When this radio was removed from the fish and pounded on a table it began to pulse again and was reimplanted in another fish. The radio was still transmitting after 499 days, when contact with it was lost.

Water conductivities during the prime tracking months of May-September, 1980-85, varied from 205 to 950 µmho (at 25 °C) and averaged about 540 µmho. Fifteen modules experienced temperature extremes from 0 to 25 °C during May 1984 to September 1985.

Radiotracking under high conductivities (greater than 700 µmho) was marginal, and this contributed to the lack of success in some cases, particularly in deeper water (Tyus 1982) and for razorback suckers, which used deeper habitats in the spring. The relative success of tracking in the Green River was due, in part, to its shallow conditions. In addition, I was able to retune search receivers to obtain greater sensitivity at the expense of not having separate channel bands, and this resulted in better contact success. Highest water conductivities occurred at lowest water levels, and the shallow water levels partially compensated for declining signal strengths. Under these marginal conditions it was necessary to check antenna connections and coaxial cable condition frequently. Poor cable linkages, damaged cables, and connector shorts were the largest contributors to tracking failure. In 1984, all receiving units were refitted from "bnc" to the larger "coaxial" connector, and this aided in reducing connector failure. Simple whip antennas were proven preferable for riverine work, and difficulties in mounting the large 40 MHz Yagi antennas were avoided. Since rivers produce natural boundaries, a directional antenna was not needed until after the general location of the fish was obtained. After a fish was located by the whip antenna, a small loop antenna was adequate to triangulate fish location.

The absolute accuracy of the fish locations from triangulation is unknown. However, individual fish were visually observed in shallow water, and although the fish could not be observed in deep water, depth measurements at the signal source always disturbed the fish. Visual observations and movements of the fish indicated that the signal source accurately pinpoints fish location. Untrained trackers should test their ability to pinpoint transmitter location by using a weighted transmitter. This method was used in training new personnel.

The effects of temperature fluctuation on the radio modules was a potential trouble area. The single known instance of transmitter failure occurred during the winter when water temperatures dropped to near 0 °C. I noted deviations in transmitted frequencies (drift) and pulse rates with radio modules. This could have resulted in tracking failure if wildlife-type tracking receivers were used, since these usually have separate and, in some cases, nonoverlapping receiving bands. All SR units were adjusted for maximum signal detection. Although some fish frequencies overlapped, different pulse rates enabled identification of individual fish. Once a radio implanted fish was detected, I was able to tune any 40 MHz frequency with the RF unit and thus confirm each identification.

This study does not suggest one transmitter or battery type is better than another. Rather, I attributed most of the observed differences in tracking success to other, unknown factors that need to be evaluated. Although my use of a ratio of the field contact period to the theoretical radio life appears to be a crude way to evaluate radiotracking success, a comparison of the average performance obtained here (47.3%) with that of other investigators indicates it is accurate. I determined this by calculating performance ratios for all other radiotracking efforts on Colorado squawfish in the Green River Basin. Radant et al. (1983), using similar equipment in the White and Green Rivers (similar water conductivities), obtained an average performance ratio of 47.6% for the eight fish they studied. Wick et al. (1983), using different type radios and receivers in the Yampa River (a smaller tributary with lower water conductivity), had a 49.6% ratio for 12 fish. [Holden and Selby (1978) implanted five Colorado squawfish, but terminated their study due to equipment failure. I did not calculate a ratio for their work.]

These results indicated that investigators using commercially available radios and tunable receivers can anticipate long-term success even in large, high conductivity rivers, if their radiotracking limitations are understood and enough radio tagged fish are used.

I found that Colorado squawfish were easier than razorback suckers to radiotrack because they used shallow habitats most of the time. Razorback suckers were more difficult to track in spring and fall because they used deeper habitats. Radios with larger, more powerful batteries could not be used because the sucker is a smaller species (≤500 mm in length).

Effects of implanted radios on fish growth were evaluated from a comparison of growth rates between recaptured implanted and recaptured non-implanted fish (Tyus 1988). Although lengths of all recaptured fish were not available, a comparison (Student's t) of the growth of 14 implanted Colorado squawfish (mean = 11.2 mm/year, SD = 10.2) indicated no difference in growth between these fish and 59 nonimplanted fish in the same size range (mean = 10.2 mm/year, SD = 11.3). Average growth rates of two razorback suckers (2.5 mm/year) from which implants were removed compared favorably with 39 nonimplanted fish (2.2 mm/year). This suggests that the implanted transmitters did not interfere significantly with feeding behavior and growth.

The ratio of radio module weight to the body weight of Colorado squawfish averaged less than 1% (Table 2). This was also true for implanted razorback suckers. Long-term tracking by Mesing and Wicker (1986) and Miller and Menzel (1986) was also associated with a radio-to-fish weight ratio of less than 1.5%. This small ratio, and the use of beeswax as a coating for the radios, may have aided in the retention of radios implanted in this study; transmitter expulsion such as that reported by Marty and Summerfelt (1986) was not observed.

EVALUATION OF BIAS IN COLLECTION DATA

Habitat data recorded at the point of capture by electrofishing for 101 Colorado squawfish in 1980 and 1981 in the Green River (Tyus et al. 1984) were compared with habitat data (1281 observations) of radio telemetered fish.

Electrofishing data were primarily taken in shoreline runs; radiotelemetry observations included more fish located in deep eddies and fewer from shoreline runs (Figure 3). The difference between the two methods apparently is due to bias in habitat types recorded for fish collected by electrofishing, caused by fish moving into the electrical field or being "herded" (Hynes 1970). The distributions of habitats recorded for both sources were tested by a Chi-square analysis, which indicated they were significantly different ($P < 0.001$). There was also a significant difference ($P < 0.005$) between corresponding substrates recorded for these fish (Figure 3). Analysis of variance (ANOVA) indicated that average depths recorded at capture locations of 91 Colorado squawfish (mean = 1.23, SD = 0.55) were significantly different ($P < 0.04$) than depths recorded for 244 observations of radiotagged fish (mean = 1.40, SD = 0.79), but corresponding velocities were not significantly different ($P > 0.5$).

Habitat data obtained by fish radiotelemetry is assumed more accurate than that obtained by electrofishing because gear selectivity and lack of efficiency can be avoided. In addition, diel and seasonal habitat preferences can be obtained for the same fish. In large, turbid river systems where conventional fish collecting techniques cannot effectively sample all habitats (and fish cannot be visually observed), radiotelemetry may be the only tool available to obtain such information.

HABITAT USE

Colorado squawfish undertook spawning migrations each year, and exhibited homing (Tyus 1985) to two major spawning areas in the Green River Basin (Figure 4). Their movement patterns were useful in partitioning the habitat data into three seasons: migration, spawning, and "adult" (remainder of the year). No habitat use data were collected during the migration periods before and after spawning, when the fish were moving.

During the July-August spawning period, radiotelemetry contacts indicated the fish were selecting deep pools or eddies, and riffles. The fish would remain in deep pools or eddies, abruptly move to cobble bars, then return. This behavior, similar to visual observations made for spawning northern squawfish (Beamsderfer and Congleton 1982), warranted the division of selected habitats into two apparent types:

(1) a resting-staging habitat in pools or large shoreline eddies where the fish may find suitable resting and feeding habitat between spawning forays or where males may gather around females until they are ready to deposit eggs, and;

(2) a deposition-fertilization habitat in riffles, where males and females congregate, females deposit eggs, and the males fertilize them.

A comparison of spawning habitats between the Green River and its Yampa River tributary (Table 3) indicated that fish in both rivers utilized similar microhabitats, and the close agreement between years (Table 3) suggested that the division of spawning habitat relative to the behavior of the fish was proper.

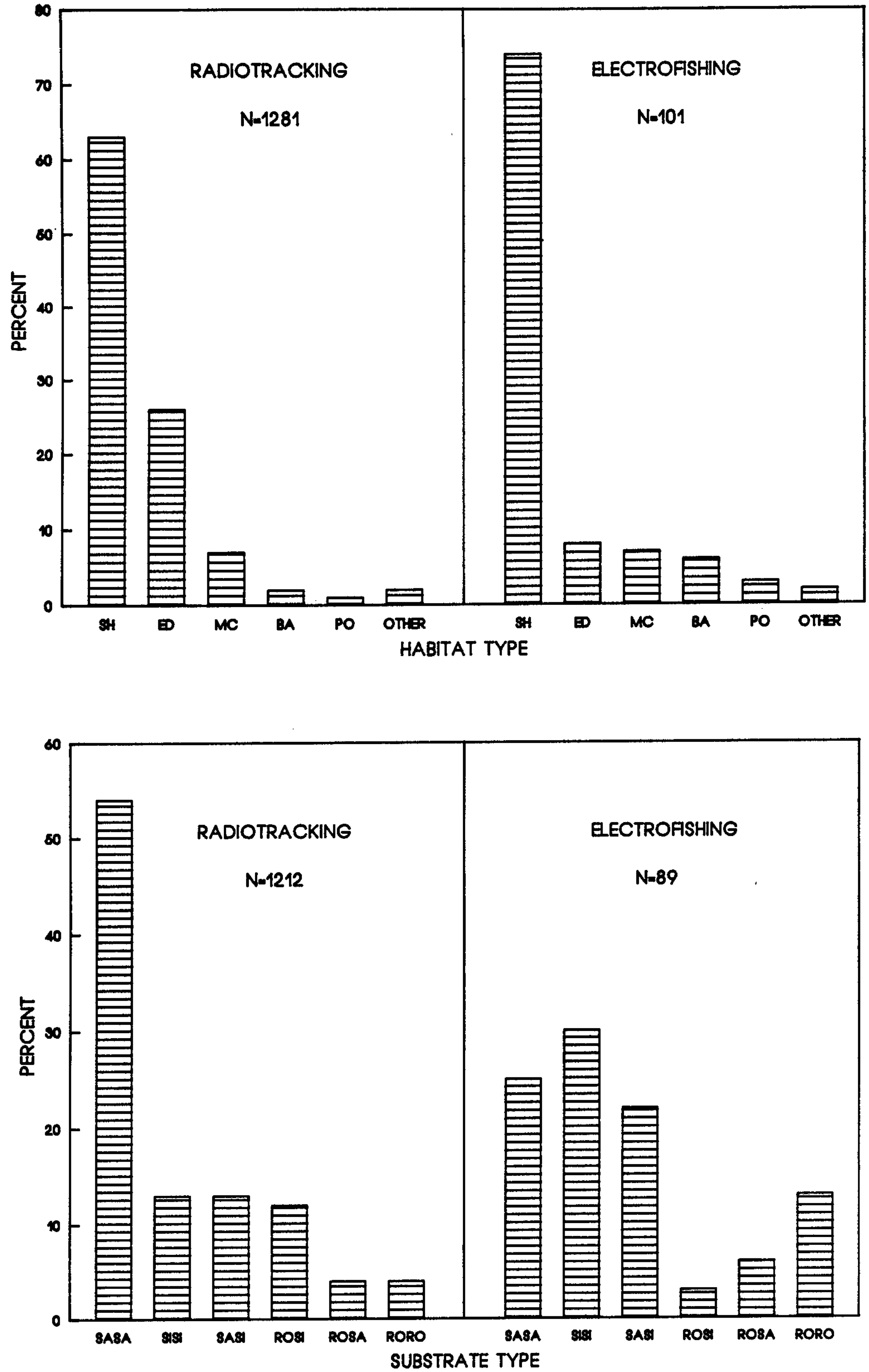

Figure 3. Habitats (top) and substrate types (bottom) recorded at point of capture by electrofishing and at triangulated positions by radiotelemetry of Colorado squawfish in the Green River, Utah.

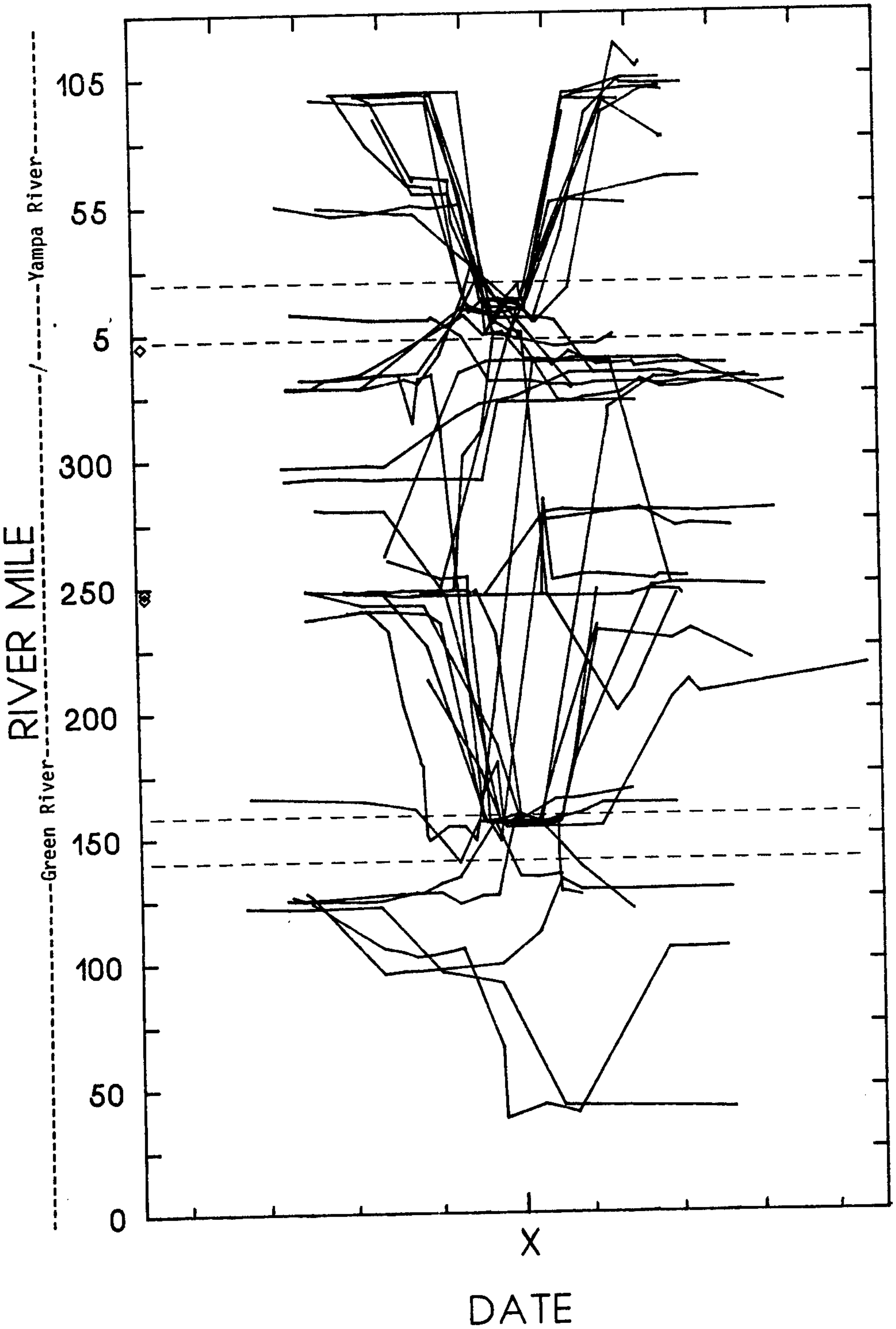

Figure 4. Movement patterns of radiotagged migratory Colorado squawfish in the Green River basin, 1980-1985 (after Tyus et al. 1987). Spawning reaches delineated by dashed lines, mouths of tributaries indicated by diamond symbols, X = midpoint of calculated optimum spawning period for each year. Data scale is for 30-day increments.

Table 3. Depth and mean water velocities recorded at locations of radio-telemetered Colorado squawfish during the spawning season, Yampa River, Colorado. n = number of fish.

Year	n	Number of contacts	Mean depth (m)	Mean velocity (m/s)
		Resting-Staging		
1981	6	68	2.23	0.43
1984	7	45	2.26	0.50
1984	5	147	1.89	0.17
Mean			2.13	0.37
		Deposition-Fertilization		
1981	5	84	1.05	0.49
1983	5	30	0.91	0.51
1984	5	45	0.87	0.45
Mean			0.94	0.48

Colorado squawfish adults were observed in a variety of habitats (Tyus et al. 1984) during the remainder of the year, usually in eddies and runs along shorelines and over sand and silt substrates (Tyus et al. 1984). Radiotelemetry indicated the fish, at times, selected drop-offs next to sand bars, both in runs and eddies. In 1984 and 1985, fish habitat utilization data for use in the PHABSIM model (Bovee 1986) were evaluated by collecting depth, velocity, and substrate data 1 to 2 m inshore (shallow) and offshore (deeper) from the signal source. Visual observations in shallow water indicated that Colorado squawfish selected sheltered habitats behind boulders or other cover. In deeper waters, the fish were most often located in eddies, where their movements suggested heavy use of the eddy-run interface (Figure 5). Depth and velocity measurements taken at the locations of 84 fish differed from the adjacent measurements (Student's t) with respect to inshore depths ($P < 0.04$; means = 1.8 m, 1.46 m) and offshore velocities ($P < 0.006$; means = 0.3 m/s, 0.53 m/s). There was no difference between depth and velocity measurements taken at fish locations (means = 1.8 m, 0.30 m/s) when these were compared with offshore depths and inshore velocities (means = 1.85 m, 0.25 m/ s). Mean inshore and offshore depths (1.46 m, 1.85 m) and velocities (0.25 m/s, 0.53 m/s) were different ($P < 0.02$ and $P < 0.002$, respectively).

These results indicate that Colorado squawfish utilize habitats that are relatively heterogenous with respect to water depth and velocity profiles. In this respect, microhabitat data recorded at the fish may not reflect the mean cell depths and velocities that are input variables for the PHABSIM model

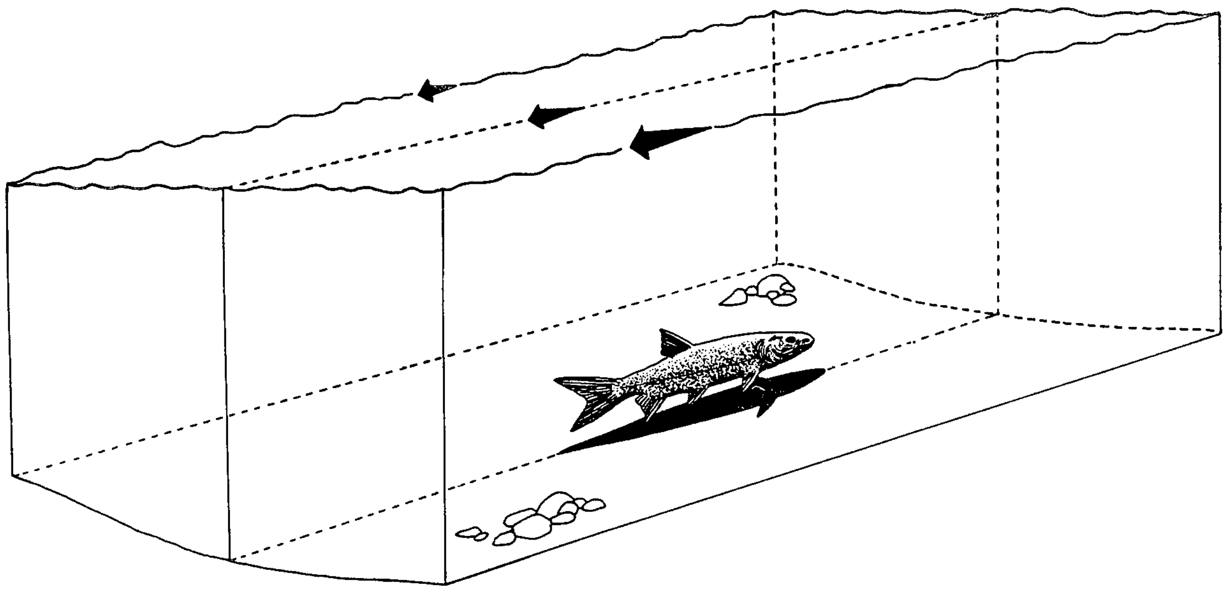

Figure 5. Illustration of depth and mean water column transections at the location of radiotagged Colorado squawfish. Depths drawn to scale; arrows are vectors of velocity.

(Bovee 1986). This would require more data points across the stream (e.g., perhaps at 1-m rather than 10-m increments) or more measurements near the fish.

Water depths and velocities recorded at the observed locations of radiotelemetered Colorado squawfish in the Green, Yampa, and White Rivers were tested by ANOVA (Tyus et al. 1984) in an effort to evaluate potential differences in microhabitats used. There was no significant difference in the depths recorded from the Green River between 1980 and 1981, but a comparison of the mainstem Green River with its tributaries indicated a significant difference ($P < 0.01$) between depths recorded from the Green River fish and fish using its two tributaries (White and Yampa Rivers). Depths recorded between the White and Yampa Rivers were not significantly different. Although an ANOVA indicated no significant differences between velocity readings for Colorado squawfish using both methods in the Green River in 1980 and 1981, velocity measurements by both methods were different ($P < 0.01$) between the Green, White, and Yampa Rivers. It is not known if these differences are due to the selection of different habitats or whether these comparisons reflect different habitats present in these rivers. The results indicate that care should be taken in lumping data until partitions between streams can be made and tested.

SUMMARY AND CONCLUSIONS

Radiotelemetry of stream fishes is a relatively new methodology that offers great promise for microhabitat studies, especially in high turbidity rivers where visual observations are impossible. Radiotracking in high conductivity waters of 400 µmho or more is marginally successful, but fishery workers can improve radio reception by understanding radio wave propagation in water and by using the most suitable equipment. Radiotracking is more successful in shallow rivers, and species like suckers, which select deeper habitats, are harder to track.

A field evaluation of different radiotransmitters indicated that the performance of fish modules was the same for two different manufacturers and for mercury- and lithium-powered radios. Success of radiotracking was evaluated relative to tracking duration and was similar for three different studies in the Green River basin. Growth rates of recaptured fish suggested that surgically implanted radios should have little effect on the behavior of the fish, and investigators should evaluate growth rates for this purpose.

Fish location and habitat use was not difficult to obtain with radiotelemetry, and the results of this study suggested that habitat data obtained by radiotelemetry were nonbiased and representative. Statistical testing between habitats recorded for fish captured electrofishing and for habitats measured for radiotelemetered fish indicated the two resultant datasets were significantly different, with respect to habitats, substrates, and depths. It is assumed that these results are due to bias inherent in electrofishing data.

Because of the large number of contacts that can be made by radiotracking fish, enough data points can be obtained to partition habitat use according to fish behavior, especially by season or habitat heterogeneity. Additional habitat measurements can be made and used to validate the application of physical habitat modelling methodology. This study indicates that a proper interpretation of fish habitat utilization in heterogeneous habitats may require more hydrologic information than is generally collected in physical habitat studies.

ACKNOWLEDGMENTS

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QUESTION AND ANSWER SESSION

Harold Tyus

Question from the floor: I read something the other day that indicated that some people think that these fish are anadromous; that when they had access to the seas, they would travel there. Do you believe this to be the case?

Tyus: Cyprinids of the group Ostariophysi are not supposed to be anadromous types. There are fish of the same group in Russia and China that look the same and exhibit similar behavior. It is unusual in North America to have this type of migratory behavior without being an anadromous species.

Campbell: It seems like the recovery efforts for this species are centered on habitat restoration, with some emphasis on culture. Do you foresee the U.S. Fish and Wildlife Service developing culture or continuing to lean toward habitat restoration and rehabilitation as the major components of the recovery plan?

Tyus: I can give you three considerations:

(1) The intent of the Endangered Species Act is to protect species in their native environment. We can't just put them in a zoo and flush the native environment away.

(2) Fish culture is playing an important role, but this role must be carefully evaluated. To maintain the genetic heterozygosity in fish, it takes a lot of reproducing adults. A study on cutthroat trout indicated that it takes 200 breeding pairs to maintain the genetic diversity in one generation. We don't have the kind of facilities for doing that with our endangered species.

(3) They may imprint. You've seen how Colorado squawfish travel 150 miles to get to the proper spawning habitat. Suppose we release fish that are imprinted to a hatchery in Dexter, New Mexico. Later, as an adult, he's got the spawning urge and he's looking for Dexter, New Mexico again. So there are some biological considerations that have to be made here. The Colorado squawfish in the Green River are reproducing quite well, we're just not getting high survivorship to adults. It's not known whether hatchery fish would do any better. The razorback sucker is not reproducing successfully. They're spawning, but we think there's heavy predation upon the young and the eggs. We have a program now to artificially spawn as many fish as we can in temporary streamside hatcheries. We raise the fry, then release and study them after one, two, and three years. Hopefully, this will get them past whatever hump there is. That approach will buy time until we learn more about that particular species and its problems.

DIRECT OBSERVATION TECHNIQUES FOR HABITAT USE CRITERIA DEVELOPMENT ON THE TRINITY RIVER, TRINITY COUNTY, CALIFORNIA

by

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and
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ABSTRACT

Field techniques used for determining anadromous salmonid habitat utilization on the Trinity River in northwestern California are described. Conventional direct observation techniques were modified to allow observations of fish in a large river. The ability to observe fish and take measurements of the standard habitat variables at their precise location was made more difficult by high velocities, low water temperatures, and poor visibility. Preliminary habitat utilization curves are included for chinook and coho salmon, steelhead, and brown trout.

INTRODUCTION

The Trinity River watershed drains approximately 2,965 square miles in Trinity and Humboldt Counties of northwestern California (Figure 1).

A major tributary of the Klamath River, the Trinity River, historically, has been recognized as a major producer of chinook and coho salmon and steelhead. The Hoopa Valley Indian Reservation borders the lower 12 miles of the Trinity, where the Hupa Indians, still dependent on salmon for subsistence and ceremonial uses, maintain a net fishery. In addition, the Trinity River basin supports other important natural resources, many of which sustain significant resource-based social and economic interests. Mineral, timber, and water resources are examples of those developed.

The Trinity River Division of California's Central Valley Project, operated by the U.S. Bureau of Reclamation, is the only major water development project in the basin and serves to export water from the Trinity River to the Central Valley of California. The keystones to this project are Lewiston Dam

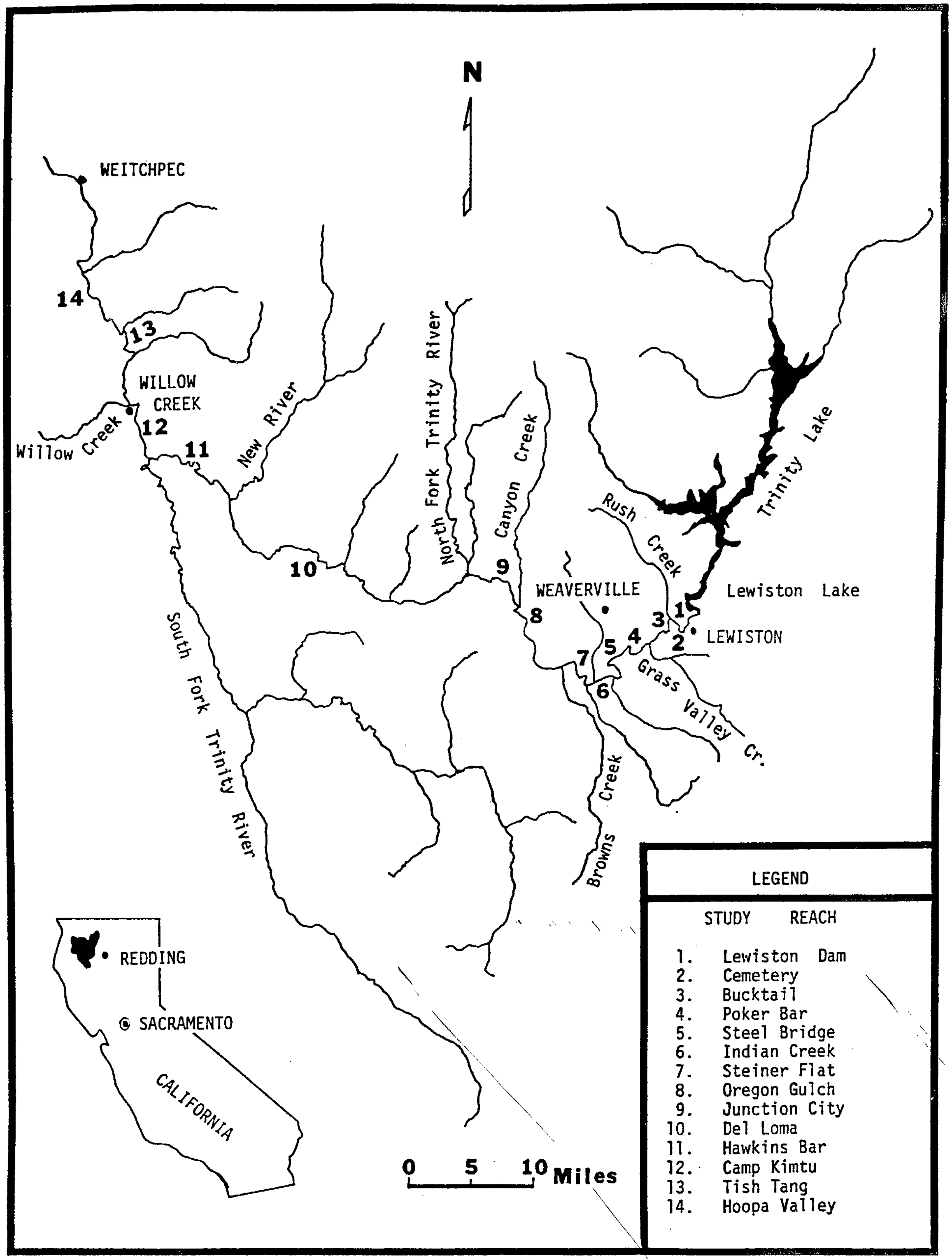

Figure 1. Map of the Trinity River flow evaluation study area.

(at river mile 110) and Trinity Dam just upstream. The former represents the upstream limits of anadromous salmonid migration in the basin. As mitigation for upstream losses the Trinity River hatchery was constructed at the base of Lewiston Dam. In addition, downstream flows were to be provided to maintain fish resources.

Coincident with construction and operation of the Trinity River Division, logging operations increased within the Trinity basin. Higher watershed erosion rates and lower streamflows below Lewiston Dam resulted in extensive sedimentation of fish habitat. Maintenance of minimum streamflow releases and operation of the fish hatchery were not sufficient to sustain fisheries populations. Salmon and steelhead populations continued to decline, and in some stocks the decline has exceeded 90 percent of former levels.

In December of 1980, the Fish and Wildlife Service and the Bureau of Reclamation reached an agreement to increase releases to the Trinity River below Lewiston Dam to aid in the rehabilitation of the anadromous fishery resources. The agreement was approved by the Secretary of the Interior in January 1981. In addition to increasing flow releases for fishery purposes, the agreement provided for a 12-year flow evaluation to monitor the fishery response to increased flows. A key element of the Trinity River flow evaluation is to develop habitat preference criteria that quantify depths, velocities, substrates, and cover requirements for each species and lifestage of anadromous salmonids of the Trinity River. Data collection was planned for a 3-year period, which began in January of 1985. Following is a preliminary report based on data collected from January 1985 through June of 1986. The fish curves presented at this time are preliminary, category II type, utilization curves (Bovee 1986).

METHODS

Sampling was conducted at 14 study sites located on the Trinity River between Lewiston Dam and Weitchpec (Figure 1).

Habitat use data were collected for all lifestages of chinook and coho salmon, steelhead, and brown trout. Data collection was accomplished through both direct and indirect sampling methods. Direct observations were made by mask and snorkel, from the bank, or from a raft during float trips. When water visability dropped below 5 feet, direct observation by mask and snorkel was ineffective, and indirect sampling methods with either a backpack electrofisher or seine were used.

Direct observation by mask and snorkel required two persons, one as the snorkeler and one to record data, operate the flow meter, and control the raft. Sampling was conducted in a downstream direction at each study site. Sampling in an upstream direction proved to be impossible due to the size of the river and high water velocities. The snorkeler worked in a zig-zag pattern across the river channel from bank to bank. At each bank, sampling in an upstream direction for short distances was done when water velocities permitted. This sampling technique allowed for nearly complete coverage of

the study site. When fish were spotted the observer determined the species, lifestage, behavior, and focal point. The support person was then signaled to approach, and the observation was completed. When fish were spotted in the thalweg, where water was too deep or swift to stand in, the observer floated motionless until out of the site. The observer then carefully approached the fish from the rear or side. Once the observer determined that the fish was not startled by his presence, the observation was made. No observations were conducted on fish believed to be startled or disturbed by the observer. When schools of juvenile salmon were encountered, the number of fish in the school was counted or estimated, and the observation was made at the focal point of the school. When one school of fish was found to occupy more than one microhabitat, additional observations were made in order to accurately represent those microhabitats used. Habitat use measurements of spawning salmon and trout were taken 0.5 feet upstream of the redd, along the centerline, in an attempt to simulate prespawning hydraulic and substrate conditions. Fish nose velocities were taken at 0.4 feet from the bottom for all spawning observations.

Habitat availability was estimated by taking a minimum of 150 random measurements at each study site for each discharge sampled (Voos 1981). The sampling locations were determined with the use of previously prepared tables of paired random numbers. The first number in the pair represented the distance downstream to the next sampling location, while the second value represented the percent distance across the river channel, yielding the exact location of the observation. Data collected during habitat availability sampling was the same as that collected for habitat utilization samples.

For indirect observations, both a backpack electrofisher and bag seine were used. Selected areas within each study site were sampled in an upstream direction with the electrofisher. When fish were sampled, the species and lifestage were noted, and a marker was placed designating the capture location. Once sampling was completed we went back to the first marker and systematically worked upstream, recording each observation. The area sampled was then measured, and habitat availability measurements were taken at 0.25, 0.50, and 0.75 of the length and at 0.25, 0.50, and 0.75 of the width, at each of the length intervals, for a total of nine observations.

Seining was done in a downstream direction over monotypic habitat types, such as gravel bars or backwaters. All fish captured were recorded for species, length, and lifestage. The area of the seine haul was then measured and representative habitat measurements were made using the same method for obtaining the habitat availability measurements described above for electrofishing.

DATA REQUIREMENTS

Fourteen habitat parameters were recorded for each observation taken using direct observation techniques. The species and lifestage were determined. Fish less than 50 mm in forklength were considered fry. Fish ≥50 mm and ≤200 mm were considered juveniles, and fish >200 mm were considered adults. An estimate of forklength was obtained with the aide of an underwater slate with a centimeter scale. When more than one fish was utilizing the

microhabitat focal point, as was often the case with schools of juvenile chinook salmon, the total number of fish was counted or estimated. The behavior of the fish was categorized as holding, roving, feeding, or spawning. The total depth and depth of fish were both measured as the distance off the bottom in feet. The depth of fish was measured as the distance from the bottom to the focal point of an individual fish or school of fish. Two water velocities were taken at each observation, a mean column water velocity and a fish nose water velocity. Mean column water velocity was measured at 0.6 from the water surface for water <2.5 feet deep. The average of the velocities measured at 0.2 and 0.8 feet from the surface was used for water ≥2.5 feet deep. Water velocities were measured with either a Marsh McBirney model 201 flow meter or a Price "A A" current meter.

A three-digit code was used to describe the cover types and quality of the cover being used by the observed fish (Table 1). The first digit describes the dominant cover type present, while the second digit describes the sub-dominant cover type, if present. The third digit, which follows a decimal, describes the quality of the cover types present as poor, moderate, good, or excellent.

The substrate composition found under observed fish was described with the Brusven substrate index (Bovee 1982). The Brusven index is composed of a three-digit descriptor of dominant substrate, subdominant substrate, and percent embedded in fines (DS.%E). The substrate categories are listed in Table 2.

The stream characteristic present at each observation was categorized into nine different habitat types (Table 3). Surface turbulence was noted as either present or absent for each observation taken. A visual estimate of the percent canopy cover was made for each observation as a percentage of the sky blocked by the riparian canopy. Additional data recorded for each sampling day included an estimate of water visibility in feet, stream discharge, study site, water temperature, weather conditions, observers present, and the date and time of sampling.

DATA SUMMARY

Habitat use data were summarized by depth, velocity, substrate, and cover. All habitat use curves were developed from data collected by direct observation, primarily by snorkeling. Habitat use curves were developed from the frequency of the number of observations of each parameter per species lifestage. The habitat use curves for depth and velocity were hand drawn by fitting a smooth curve through a normalized frequency distribution for each species and lifestage.

Normalized bar histograms were used to show habitat use for substrate and cover. All of the substrate curves were drawn from the dominant substrate value observed. When the study is complete, cover and substrate curves will be constructed in their entirety using the Brusven index.

Table 1. Cover code descriptions used to develop habitat utilization criteria for the Trinity River flow evaluation, Trinity Co., California, 1986.

Code	Cover type	Description
0	No cover	Gravel less than 2 inches or any larger material that is embedded to the extent that no cover is available
1	Cobble	75 to 300 mm and larger, clear of fines
2	Boulders	300 mm and larger, clear of fines
3	Small woody debris	Brush and limbs, less than 9 inches in diameter
4	Large woody debris	Logs and rootwads greater than 9 inches in diameter
5	Undercut bank	Undercut at least 0.5 feet
6	Overhanging vegetation	Within 1.5 feet of the water surface
7	Aquatic vegetation	

Recorded as DS.Q, where D = dominant cover type, S = subdominant cover type, Q = quality of cover.

PRELIMINARY RESULTS

Table 4 summarizes the number of observations and total frequency of fish observed or collected from January 1985 to June 1986. During this 2-year period, a total of 18,555 fish were recorded in 2,418 observations.

Preliminary habitat use curves for all lifestages of chinook and coho salmon are illustrated in Figures 2 through 7. Curves for all lifestages, except spawning, of steelhead trout and brown trout are illustrated in Figures 8 through 13. Use curves for cover and substrate were based only on the dominant category observed.

Table 2. Expanded Brusven substrate index used for habitat utilization criteria development, Trinity River flow evaluation, Trinity Co., California, 1986.

Code	Substrate type	Size range (mm)
0	Fines	<4
1	Small gravel	4 - 25
2	Medium gravel	25 - 50
3	Large gravel	50 - 75
4	Small cobble	75 - 150
5	Medium cobble	150 - 225
6	Large cobble	225 - 300
7	Small boulder	300 - 600
8	Large boulder	>600
9	Bedrock	

Table 3. Stream character descriptions used for habitat utilization criteria development on the Trinity River, Trinity Co., California, 1986.

Code	Stream character
1	Pool
2	Run
3	Riffle
4	Side channel
5	Off channel ponding (beaver ponds)
6	Backwater
7	Water's edge
8	Pocket
9	Bar

Table 4. Summary of habitat criteria data collected by direct observation in the Trinity River from January 1985 to June of 1986, Trinity Co., California.

Species	Life stage	Number of observations	Number of fish
Chinook	Fry	594	7583
	Juvenile	356	6364
	Adult	12	92
	Spawning	278	342
Coho	Fry	152	1314
	Juvenile	118	925
	Adult	13	37
	Spawning	102	198
Steelhead	Fry	33	117
	Juvenile	420	933
	Adult	117	208
	Spawning	20	10
Brown	Fry	55	146
	Juvenile	104	235
	Adult	41	48
	Spawning	3	3

DISCUSSION

The use of indirect sampling techniques, such as electrofishing or seining, do not allow for accurate focal point or fish behavior determinations (Bovee 1986). For this reason, only data collected through direct observation techniques is used in the development of habitat utilization curves presented in this report.

It has become evident, after 2 years of field observations with mask and snorkel, that certain lifestages and species of fish are more easily observed than others. Holding chinook and coho salmon adults are particularly wary and easily startled in the presence of a diver. A diver should approach these fish slowly and cautiously from the rear, along the rivers edge, using cover items and shadows for concealment. In deep pools, observations on adult salmon are difficult for a skin diver because of breathing limitations, which rarely allow enough time to obtain accurate information regarding fish size, behavior, or focal point determination. Collection of accurate depths and

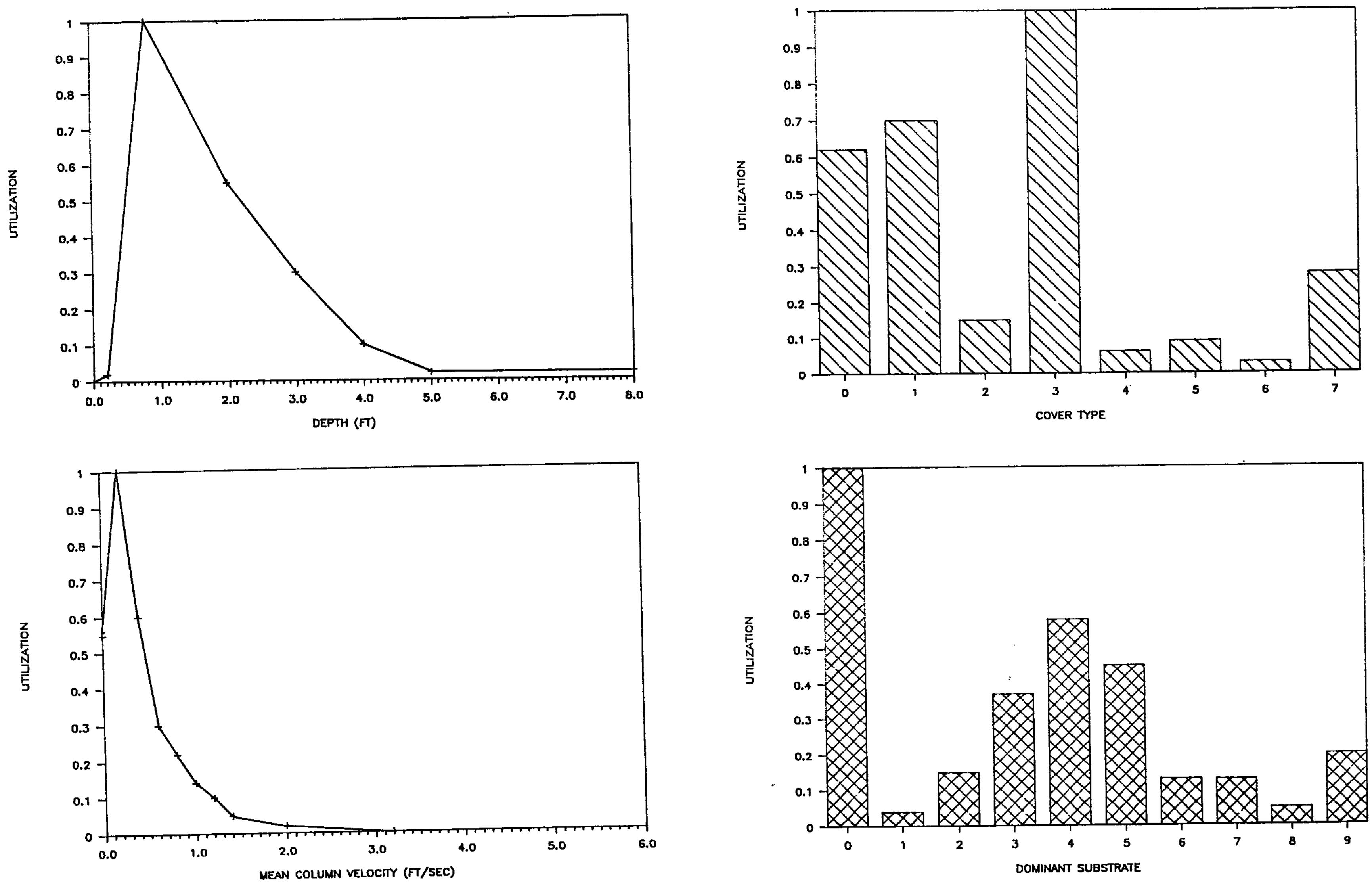

Figure 2. Preliminary habitat use criteria for chinook salmon fry of the Trinity River, California, 1986.

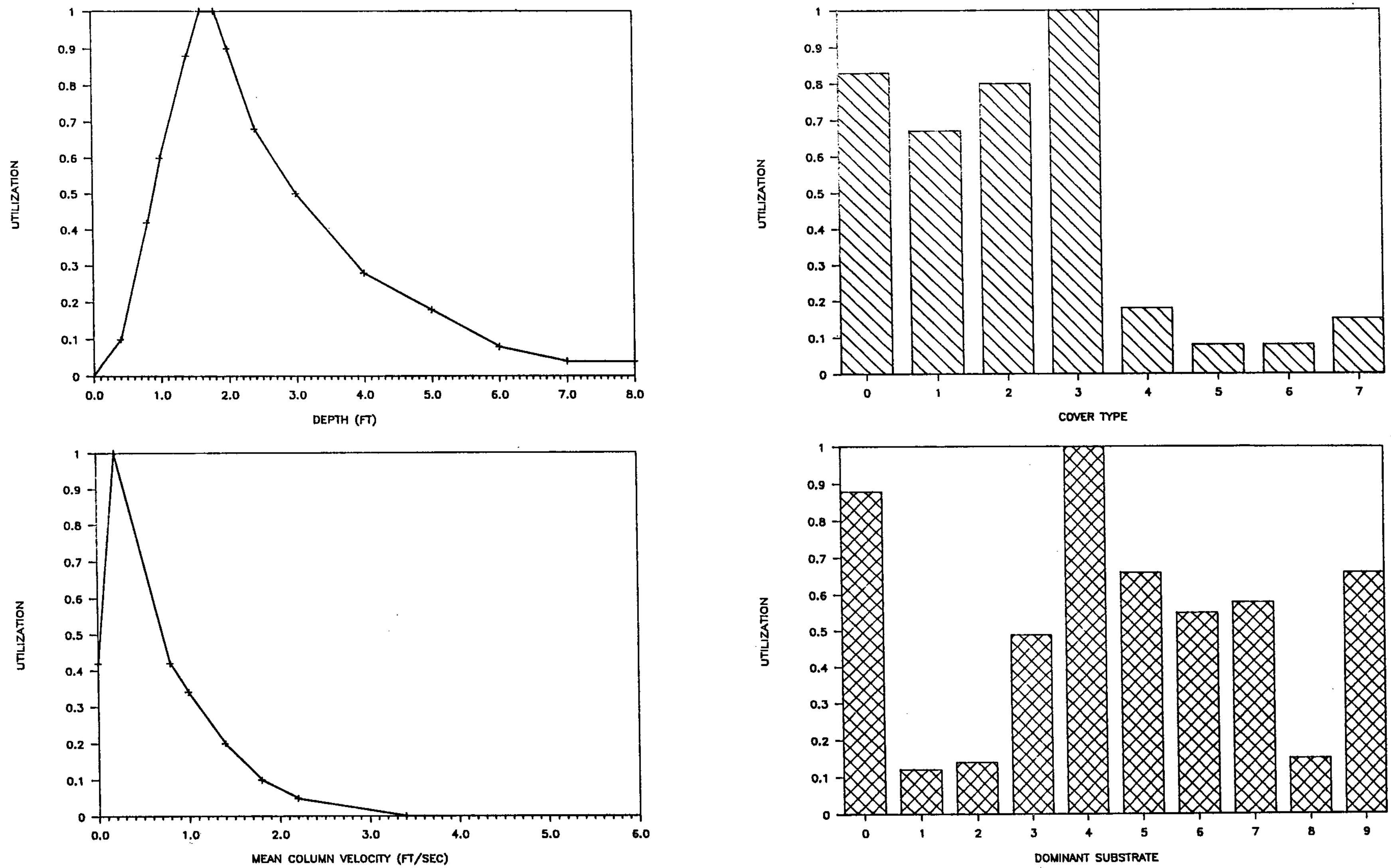

Figure 3. Preliminary habitat use criteria for chinook salmon juveniles of the Trinity River, California, 1986.

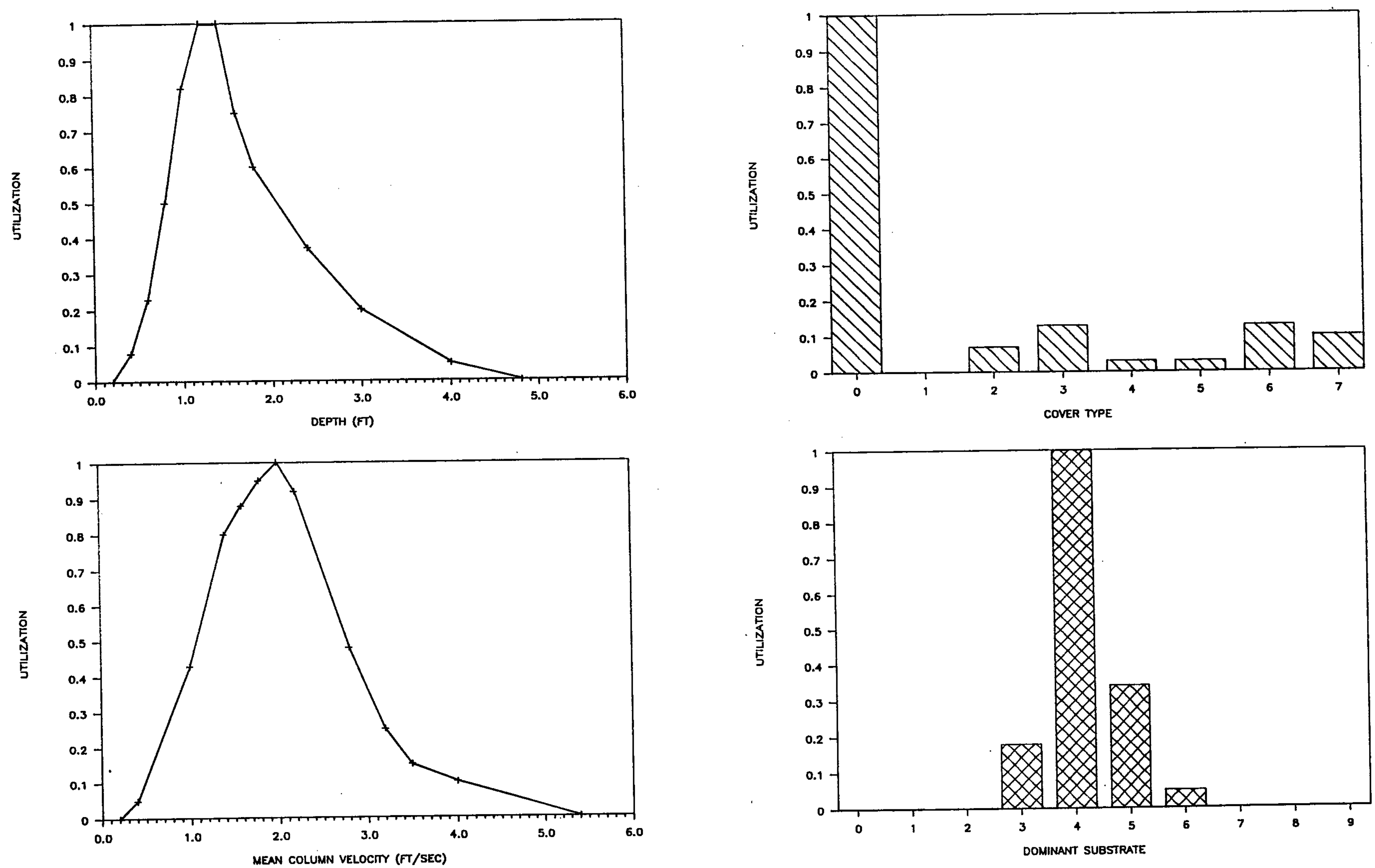

Figure 4. Preliminary habitat use criteria for spawning chinook salmon of the Trinity River, California, 1986.

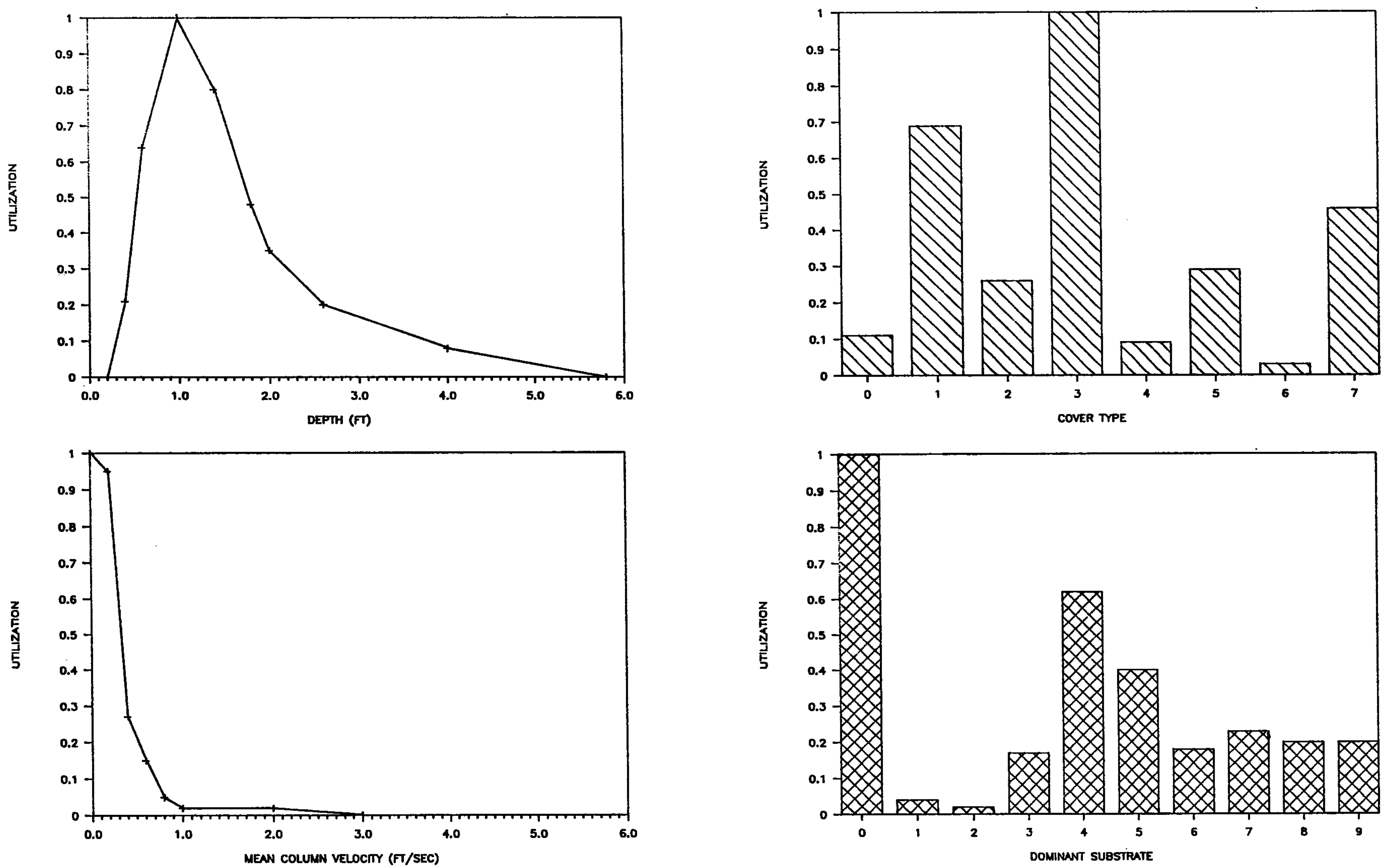

Figure 5. Preliminary habitat use criteria for coho salmon fry of the Trinity River, California, 1986.

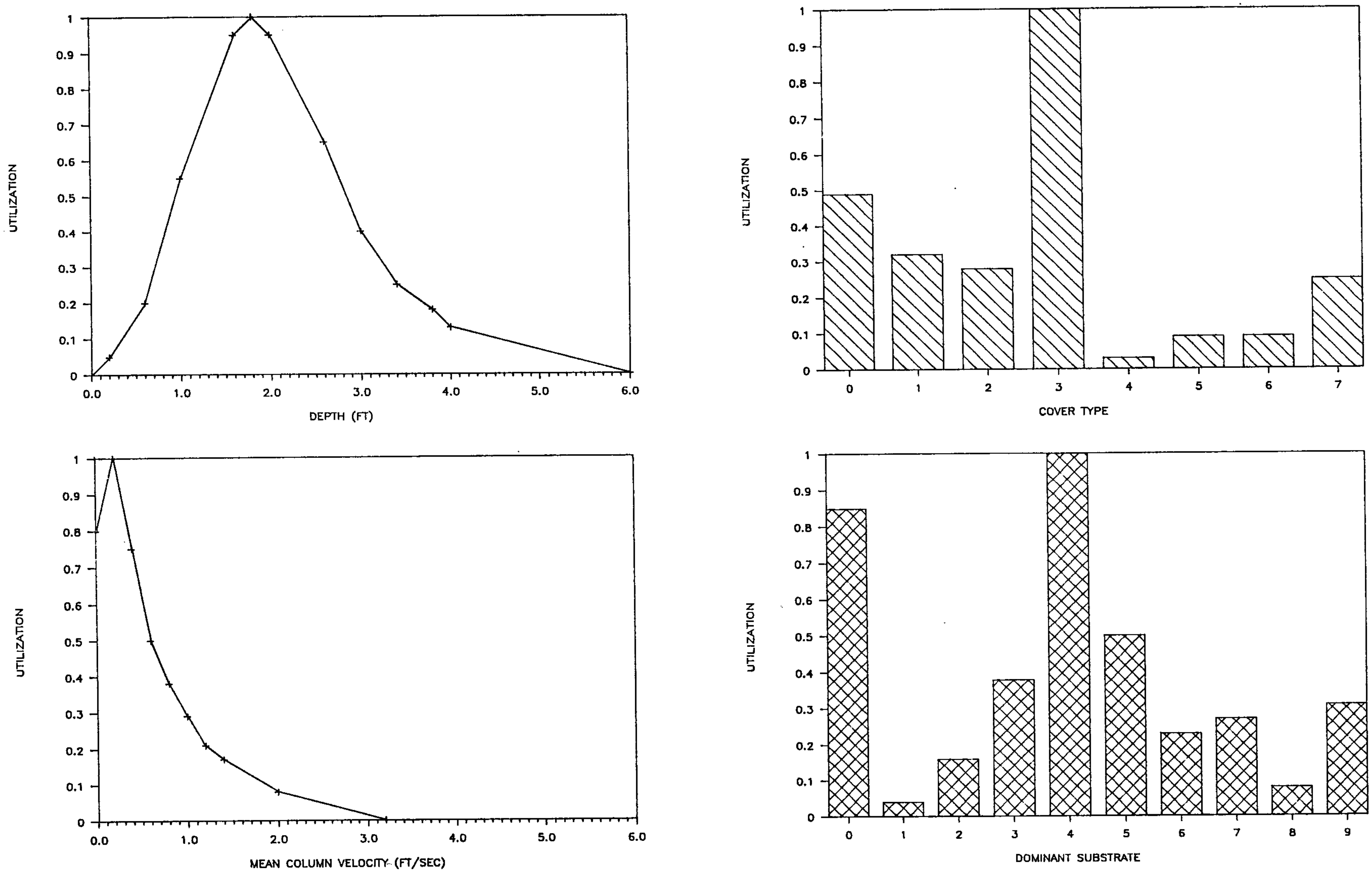

Figure 6. Preliminary habitat use criteria for coho salmon juveniles of the Trinity River, California, 1986.

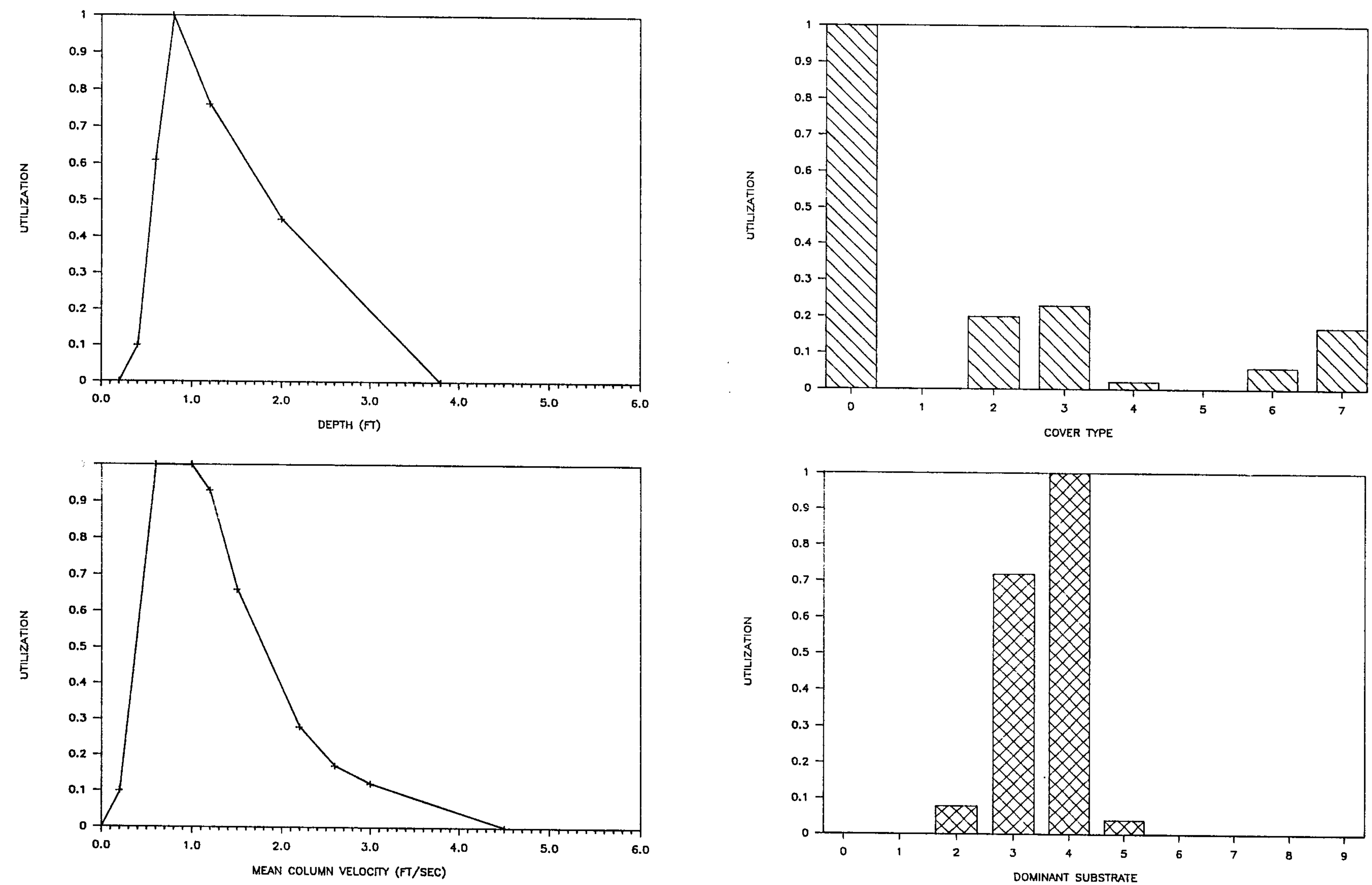

Figure 7. Preliminary habitat use criteria for spawning coho salmon of the Trinity River, California, 1986.

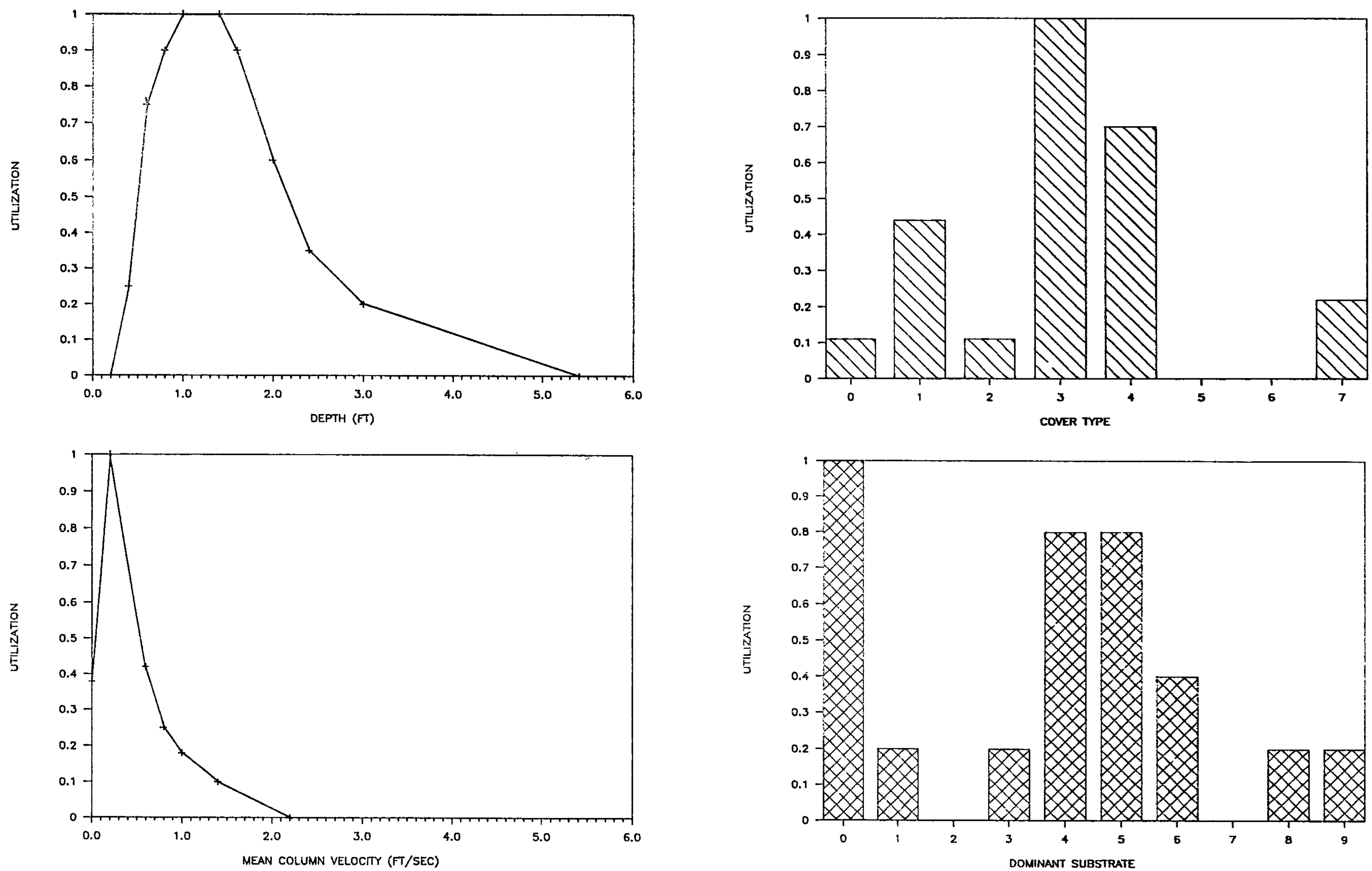

Figure 8. Preliminary habitat use criteria for steelhead trout fry of the Trinity River, California, 1986.

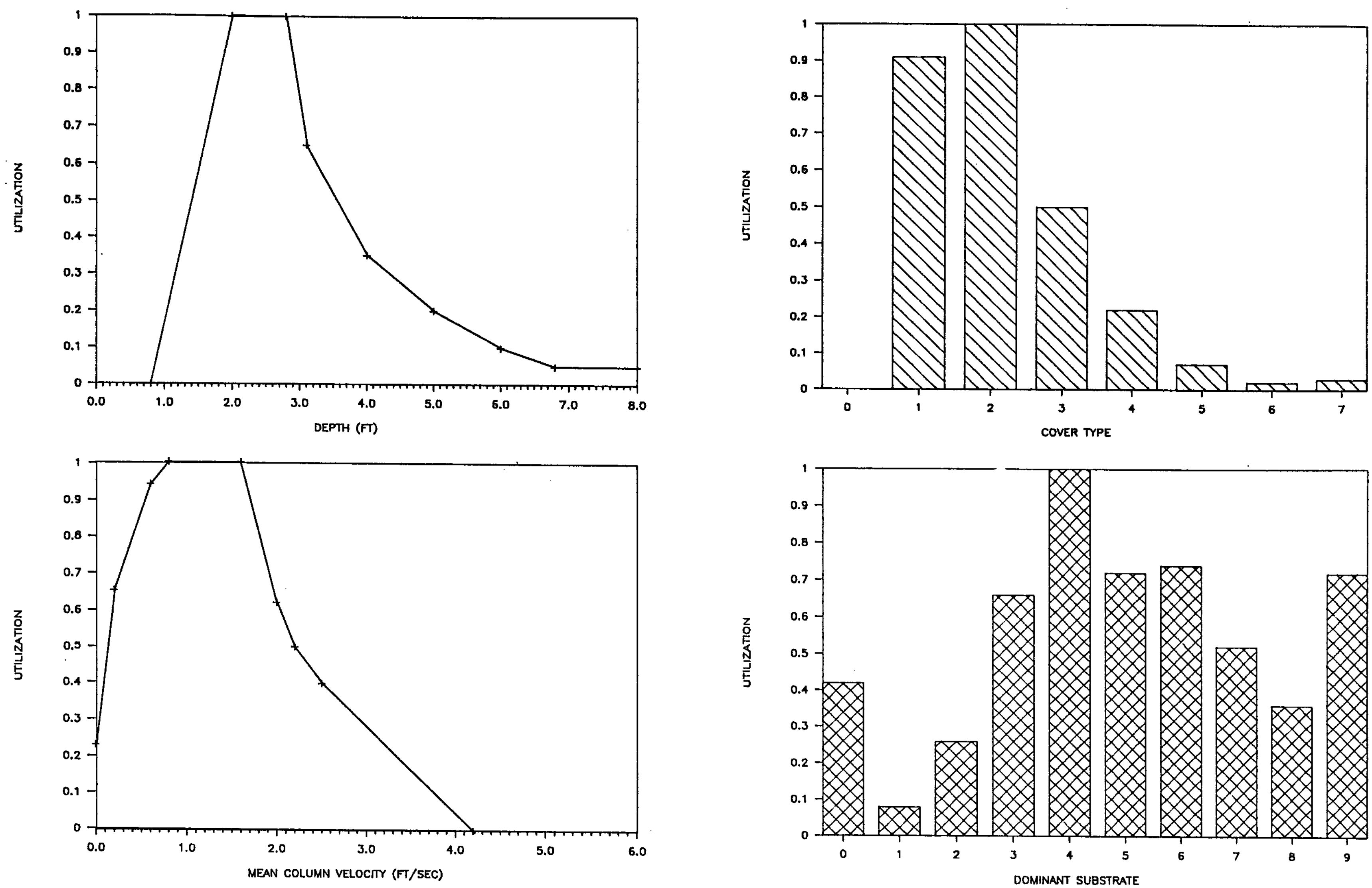

Figure 9. Preliminary habitat use criteria for steelhead trout juveniles of the Trinity River, California, 1986.

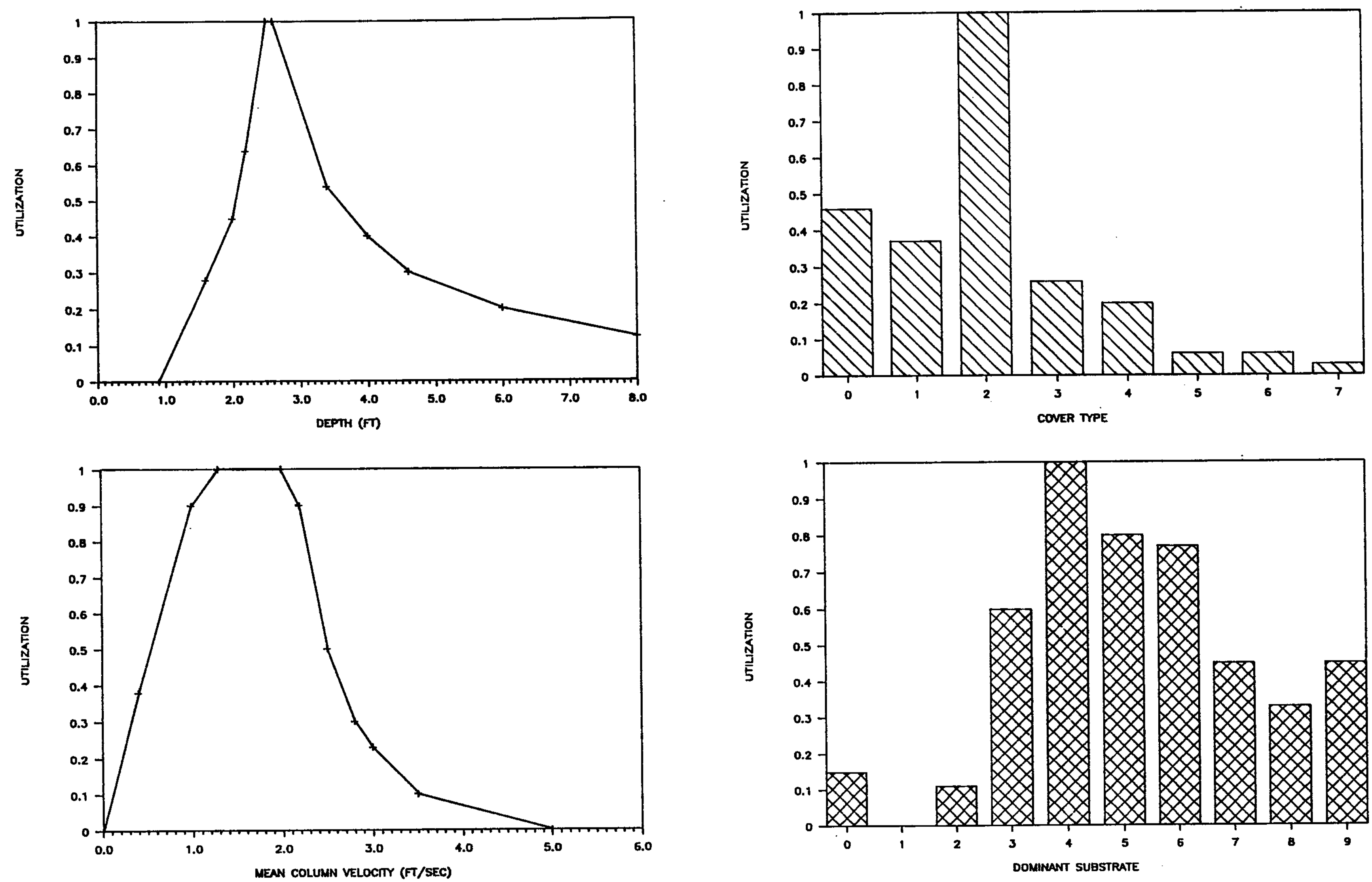

Figure 10. Preliminary habitat use criteria for holding steelhead trout adults of the Trinity River, California, 1986.

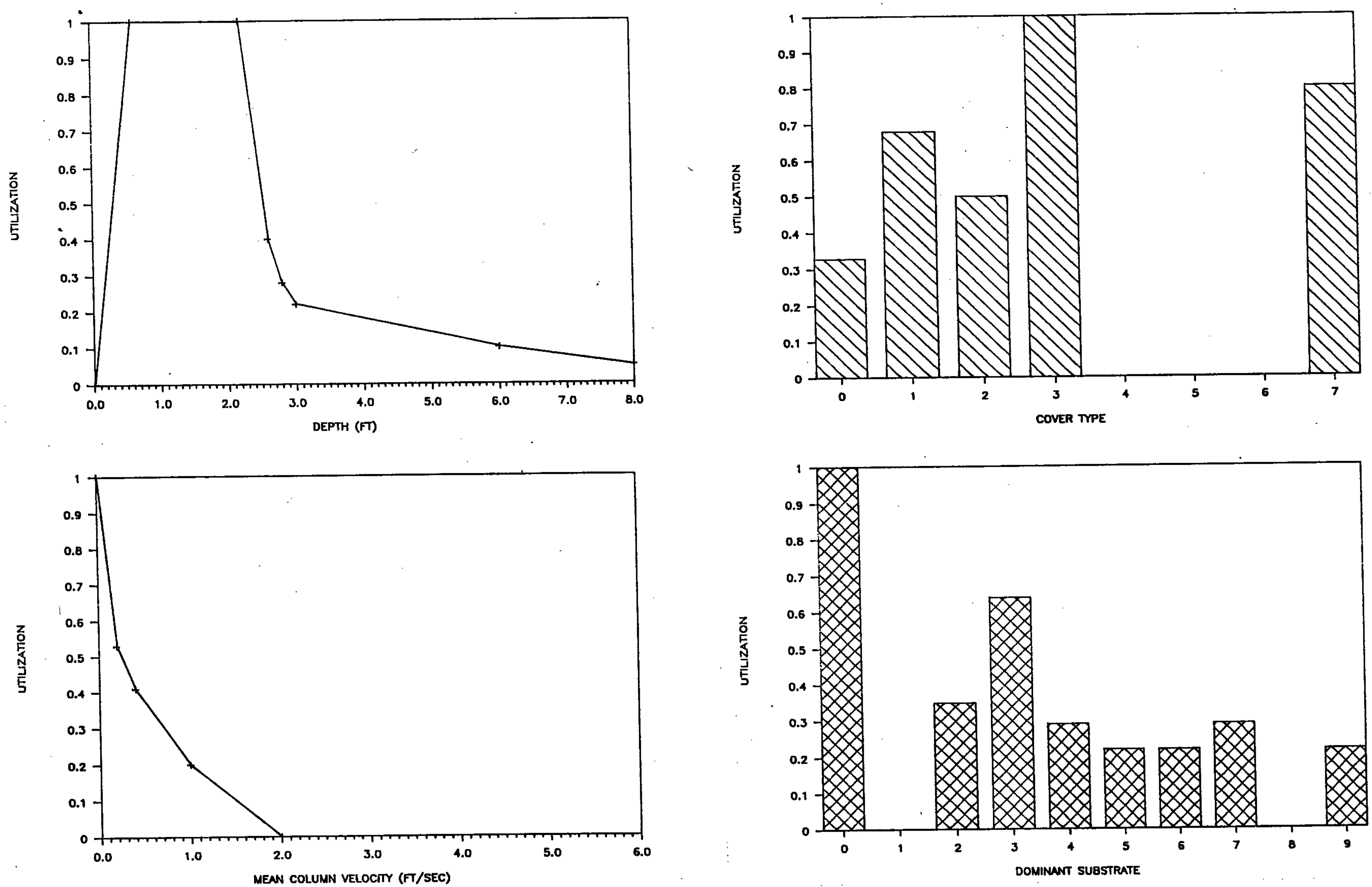

Figure 11. Preliminary habitat use criteria for brown trout fry of the Trinity River, California, 1986.

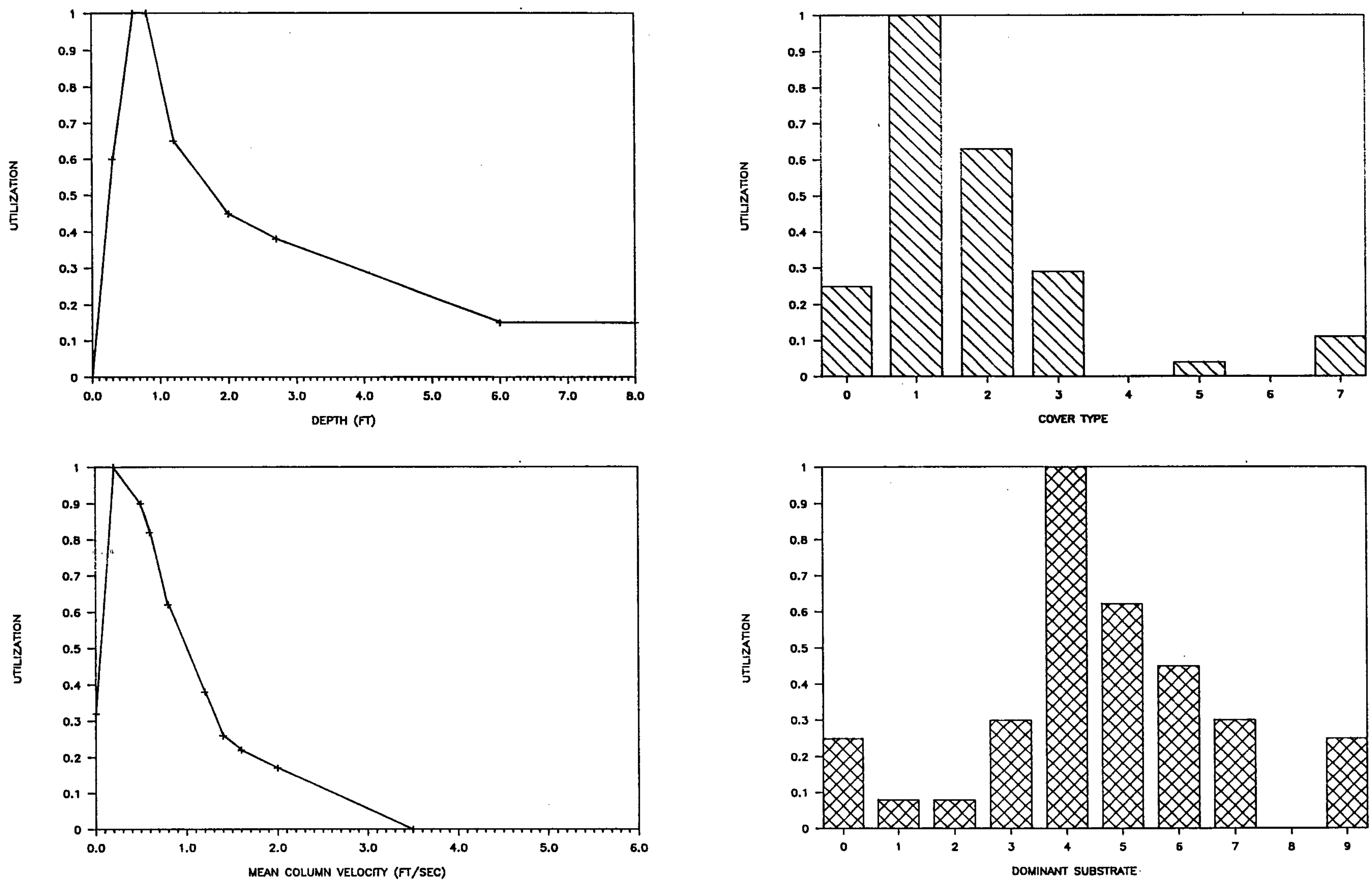

Figure 12. Preliminary habitat use criteria for brown trout juveniles of the Trinity River, California, 1986.

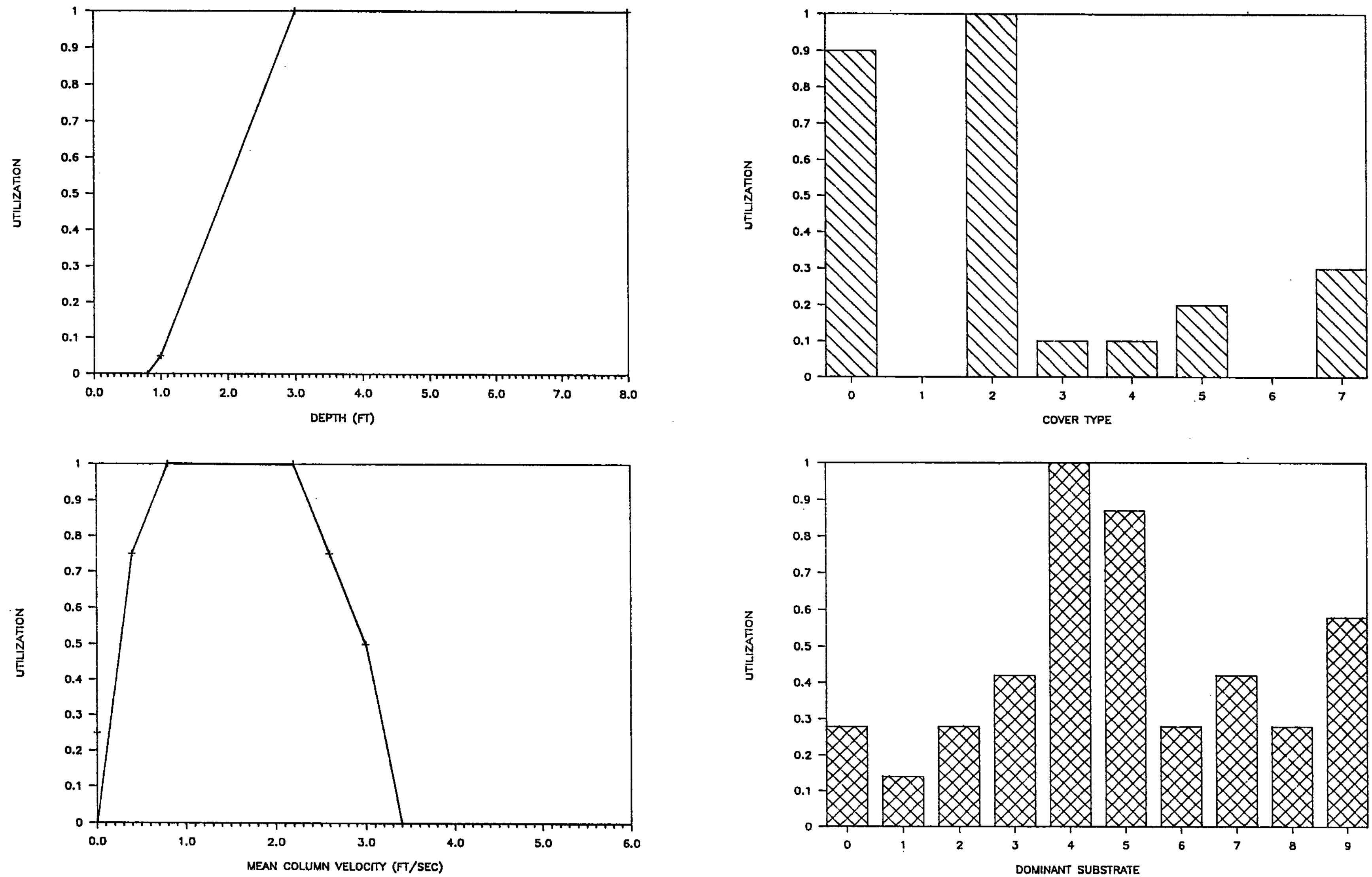

Figure 13. Preliminary habitat use criteria for holding brown trout adults of the Trinity River, California, 1986.

velocities is another problem that has been encountered when sampling deep-water areas. The use of SCUBA or hookah would greatly improve sampling efficiency in these instances. Development of adult holding curves has been low priority until this year, and there should be no problem in obtaining an adequate number of observations for accurate habitat use criteria development in 1987.

Spawning chinook and coho salmon are easily observed and are rarely startled by a cautious diver. Some spawning salmon, either male or female, may actually display aggressive behavior towards a diver that approaches too close to an active redd. Exaggerated swimming motions, fin erection, and mouth-open charges are all common reactions that have been observed. The habitat utilization curves presented for chinook salmon spawning are based on 278 observations and appear to be of good quality. More observations are needed for final development of the coho salmon spawning habitat use curves, which are currently based on 102 observations.

In most instances, a careful diver can approach fry and juvenile chinook and coho salmon and obtain all the needed habitat use information without startling any fish. When fry or juvenile salmon are spooked into cover by the presence of a diver, we have found that if the diver will back up 1 to 2 feet and remain motionless for 1 to 2 minutes all of the juveniles will usually return to their previous behavior, allowing the diver to complete the observation. The habitat use curves developed for fry and juvenile chinook salmon are based on 594 and 356 observations. The habitat use curves for fry and juvenile coho salmon are based on 152 and 118 observations. Further data are needed on juvenile coho salmon before those habitat use curves can be considered adequate.

Juvenile steelhead and brown trout are seldom startled by a diver. In fact, the exact opposite is often the case. A diver may actually attract juvenile trout by dislodging food items while moving over substrates or through cover. The habitat use curve presented for juvenile steelhead is based on 420 observations and is of good quality. Only 33 observations have been made on fry steelhead by direct observation with mask and snorkel. We believe that the majority of fry steelhead rear in the tributary streams of the Trinity River, where the majority of steelhead spawning occurs, until they reach a larger size, at which time some migrate into the mainstem. Effort will be directed at obtaining more observations on fry steelhead in the spring of 1987.

Only 14 observations have been made on spawning steelhead since the beginning of data collection in January 1985. There are two reasons for this: (1) the majority of steelhead spawn in tributary streams to the Trinity River; and (2) high stream flow combined with low visibility have prevented sampling by direct observation during the steelhead spawning season. Greater effort will be placed on attempting to get an adequate number of observations for habitat use criteria development on spawning steelhead in the winter and spring of 1987.

Divers find brown trout to be the most difficult salmonid to locate in the Trinity River. Unlike other salmonids, brown trout fry, juveniles, and adults are often observed sitting on the stream bottom, perched up on their

pectoral fins, much like a goby. This behavior, combined with their brown to yellow coloration, allows brown trout to blend in with the substrate, causing them to be easily overlooked by the observer. More data are needed before final development of quality habitat use criteria for all lifestages of brown trout.

When water temperatures drop below 48 to 50 °F, juvenile coho salmon, steelhead, and brown trout bury themselves in the substrate or hide inside areas of heavy cover, such as aquatic plants or woody debris. Locating these overwintering salmonids by direct observation is a labor intensive and inefficient process. Once fish have entered the substrate, indirect sampling with a backpack electrofisher has proven to be an effective method to obtain habitat use criteria for overwintering salmonids.

In 1987, some habitat use criteria will be collected at night, in order to determine if habitat requirements change as a result of diel fluctuations.

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QUESTION AND ANSWER SESSION

Mark Hampton

Nelson: Did you notice any response from the fish to the orange and yellow markers that were used to mark fish locations?

Hampton: I stopped using colored markers to mark fish locations soon after the study was underway. The markers were awkward to carry underwater and the goody bag that was used to hold the markers constantly got hung up in the brush or on jagged rocks. In place of the markers I started using sticks or small rock piles to mark fish locations. A small underwater slate attached to either wrist was used to record any notes that were of interest or could help with remembering specific observations.

Nelson: Did the raft-support person have a lot of free time while waiting for the snorkeler to get an observation?

Hampton: When there is only one snorkeler, the support person does tend to have some slow periods. We found that two snorkelers for each support person is probably the optimum situation for sampling efficiency. The use of three snorkelers would probably be too much for the support person to keep up with, and I think that you would find that the snorkelers would be waiting on the support person. In cold water, this wouldn't be a pleasant day for the snorkelers.

Hanson: Are the curves presented here utilization curves?

Hampton: The curves presented in this report are preliminary category II utilization criteria. Category III preference criteria will be developed at the end of the study and should be available in 1988.

Sheppard: Do you feel that species interactions influence behavior and habitat selection?

Hampton: We have often observed chinook and coho salmon fry and juveniles cohabitating the same microhabitats with no apparent aggressive behavior directed towards the other species. It doesn't appear that any of the species juveniles have any significant influence on habitat selection.

Lifton: Did you attempt to deal with the spring run chinook salmon to see if any of these fish were utilizing the tributary streams?

Hampton: Our study was limited to the mainstem of the Trinity, therefore I really can't answer your question as to whether there are any distribution differences between the spring and fall chinook salmon runs within the basin. In the mainstem, I did not differentiate between the spring and fall run for two reasons: first, the habitats that are available to each run for spawning

are equal because of controlled flow, and second, because I didn't feel confident in my ability to distinguish between the two runs while collecting data when the runs overlap during the spawning season.

Payne: I noticed that in your results the number of spawning observations exceeds the number of fish. Could you explain how this could happen?

Hampton: In some instances we made observations on newly completed redds even though the adult fish may not have been present at the time of the observation. This was only done when we were confident of the species that had constructed the redd and we knew that flow conditions had not changed since the time the redd was constructed.

Question from the floor: How did you identify the different species in the field when dealing with fry and juvenile salmonids?

Hampton: At the start of the study we did have some questions as to species identification. In order to verify our field identifications, we would periodically capture some fish and identify them in the laboratory. We also took advantage of Trinity River Hatchery, where we could get easy access to live samples of known species. The hatchery personnel were also very helpful in pointing out characteristics that assisted in our field identification. After some field experience observing the different species, you start to notice that some behavioral characteristics can assist in confirming species identifications.

Question from the floor: Were there any problems with the raft spooking fish before the snorkeler could obtain observations?

Hampton: The raft was always kept far upstream of the snorkeler when fish observations were being made. This prevented any means of the raft to affect fish behavior. If the raft did get downstream of the snorkeler, the area that may have been influenced by the raft was not sampled.

Question from the floor: Did you make any observations on hatchery fish?

Hampton: We tried not to take any observations on fish known to be of hatchery origin. We kept informed of hatchery releases and knew when to be aware of their presence.

MEASURING MICROHABITAT IN SWIFT WATER

by

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INTRODUCTION

Direct underwater observation is the most effective technique to measure habitat selection by fish, offering a number of advantages over other methods. Fish species can be accurately identified, size can be estimated with precision, behavior can be observed, relative position in the water column can be determined, and other environmental variables, such as substrate and cover, can be readily and accurately assessed. No other method of documenting fish microhabitat use determines these variables with the ease and precision of underwater observation.

Until recently, direct underwater observation of fish microhabitat was limited to small- or medium-sized streams, daylight hours, warm-water months, and clear water. Large, swift streams were generally thought to have water velocities and turbulent flows, which made them unsafe for underwater observation techniques. This report deals primarily with direct underwater observation in such streams. Most of the techniques were developed with snorkel divers, but are probably adaptable to SCUBA. The techniques described worked well for me; however, all diving situations are not the same, and the techniques and equipment presented may be adapted to fit specific conditions and needs.

DIVING EQUIPMENT FOR STREAMS

The main difference between diving in the ocean and in streams is that divers must overcome the constant conductive heat loss due to flowing water. The colder or faster and more turbulent the streamflow, the greater the potential for heat loss. To prolong observation time in flowing water, a diver needs a protective suit that reduces heat loss. I recommend the use of a dry suit in extremely cold water, since a dry suit is generally "warmer" than a wet suit. A dry suit does not have a film of water to warm or rewarm,

which costs body energy and reduces observation time in the water. There are two types of dry suits, one made of neoprene and the other of PVC or hypalon-coated ballistic cloth. Both types of suits have waterproof seals at the collar, sleeve, and leg cuffs. Each type has advantages and disadvantages. Neoprene suits do not require a special inner suit for insulation because the neoprene provides the thermal insulation and a suit leak generally does not cause a rapid chilling of the diver. Additionally, these suits are generally loose-fitting, so one size (almost) fits all. Neoprene suits have a waterproof zipper across the back at the shoulders, making entry and exit difficult. PVC or hypalon suits do not have the insulating properties and require a special polypropylene fleece jumpsuit or other insulating clothing to be worn. Unlike neoprene suits, a leak in a PVC or hypalon suit generally has an immediate chilling impact on the wearer. PVC/hypalon suits may have a zipper across the shoulders or diagonally across the chest. The front zipper makes putting the suit on and taking it off considerably more convienient. PVC/hypalon suits are less flexible than neoprene suits and are therefore more size specific.

There are three additional disadvantages to dry suits. First, the waterproof seals tend to be constricting, numbing the hands, feet, and head due to reduced bloodflow. These constrictions may induce claustrophobic feelings in some divers. Second, dry suits are susceptible to damage; sharp sticks, pointed rocks, fish hooks, and normal wear and tear cause leaks in dry suits. In addition, the waterproof zippers cannot stand much abuse and their repair is expensive. Third, dry suits are expensive; they cost at least twice as much as a custom wet suit.

As an alternative to dry suits, I have had good success with wet suits. Although wet suits require energy to warm a film of water, I have found that they meet my needs under most conditions. The key to staying warm in a wet suit is keeping the same water film in the suit and not having to constantly warm new water. Contrary to popular belief, a wet suit must not be tight fitting; it should fit comfortably and properly. It must not constrict or bind, especially in the axillary region, behind the knees, or in the crotch. Tight-fitting or binding suits may cause chaffing or numbness. These problems may reduce diving time and surely will distract the diver from collecting precise data. Another popular belief is that thickness in a wet suit increases warmth. The thickness of the suit will not matter if the suit allows virtually constant exchange of cold water. Thickness matters only when the diver dives deep enough for water pressure to compress the neoprene to less than 1/8 inch. The depth necessary to compress neoprene to that thinness, however, is not approached in swift-water diving. In addition, thickness increases the probability of chaffing and restricts arm movements that are necessary in swift-water work. Design and fit are all-important in keeping a wet suit thermally efficient. It is most probable that the use of ill-fitting or badly designed wetsuits has reduced diving time in streams and has caused divers to try dry suits.

I use a custom made 3/16-inch wet suit and have stayed in 39 °F water in a stream for about two hours without chilling. The hood covers my entire chin and temples to prevent heat loss in these areas, and it fits comfortably around my jaw so that my salivary glands are not contricted. The apron of my hood covers most of my shoulders. The farmer-john-style pants add additional

layering, reducing water exchange and causing greater travel distance for the water before it reaches the torso, and thus more time to warm. The collar is where most water enters the suit because of streamflow and the upstream direction the observer usually orients to. Make sure the collar on your suit is not a funnel inviting cold water in. The jacket collar on my suit is tall. It is made of 1/8-inch neoprene, to be flexible, and fits around the base of my head. It therefore conforms to head movements and minimizes cold water surges from entering at the collar. The zipper on my jacket is only 3/4-length, reducing the potential water transfer from this source. The zipper begins near my sternum and runs diagonally to my hip. This design reduces zipper buckling. There are no zippers on the leg or sleeve cuffs to let cold water in. In addition to design and fit, there are additional steps that will increase thermal efficiency of wet suits. Thermal undergarments worn under the wetsuits impede water movement and increase thermal efficiency. Gary Smith, California Department of Fish and Game, wears woolen fishnet longjohns. The fishnet acts as little check dams that restrict water movement. I use polypropylene longjohns and like the dry feeling they provide. Gary also uses a custom 1/8-inch neoprene short-sleeve vest under his suit to restrict water movement and to add layers when he is diving in extremely cold water. He has found sewn-through seams in the suit and vest to be good sources of cold water. Gary has used this set-up in the eastern Sierra Nevada and in the Lake Tahoe basin in water ranging from 36 to 42 °F for over three hours without chilling. Spine pads also reduce water movement, but I do not recommend them because they tend to chafe. Spine pads assume that the spine does not move, but it does.

Diving gloves are a necessity in cold water. However, they all leak through the seams, so sealing the seams with neoprene cement is a must. Gary Smith uses woolen gloves under diving gloves for additional warmth in very cold water. Don't forget to use larger than normal outer gloves to accommodate the thickness of the wool or they will constrict the blood vessels and quickly numb the hands. Using velcro wrist bands on the gloves is another way to reduce or restrict water movement.

Keep feet warm with diving boots. While working in shallow water, I prefer to use wading boots rather than diving boots because they give greater support and more protection from stone bruises. Gary Smith uses "Korkers" with his diving boots for the same reason. Knee and elbow pads reduce the wear and tear on the diving suit in shallow water. In deeper water, where fins are necessary, I prefer using fast response fins commonly used by body surfers, e.g., "Custom Duck Feet," "Churchills." "Jetfin"-type fins are prone to being washed off and also tend to cause cramps in the arch of the foot or calf. Full-footed fins also tend to wash off easily, even with fixed palms.

Small displacement diving masks work best in swift and turbulent water. They offer less resistence to streamflow and are less likely to be washed off. Silicon masks do not deteriorate from ultra-violet exposure and are more durable than rubber masks. I prefer black silicon masks because they provide greater visual contrast, i.e., they limit distracting light entering the mask from the sides more than do translucent models. Purge valves on masks should be taped closed in swift water because turbulent and/or fast flow can cause the valve to leak.

I prefer using snorkels without purge valves. Snorkels with purge valves should also have their valves taped shut because the purge valve may leak. Unexpected water in the snorkel is dangerous; the diver can choke since he is expecting to breathe air but will inhale water instead. I use standard diameter snorkels, since the magnum barrel snorkels are more difficult to clear.

Direct observation activities in swift water are generally done from the surface, so weight belts are rarely necessary. However, in certain circumstances, a weight belt may be necessary. A weight belt or standard belt has a spin-off benefit, restricting water flow within the wet suit.

If you believe a knife is necessary, use a double-edged one. It eliminates guesswork as to which edge is the cutter and saves time in emergencies.

My SCUBA experience in streams is limited; however, here are a few observations. A combination of fast, turbulent water and rocks in the stream may result in a tank being punctured or valve seating ruptured, making SCUBA tanks potential bombs or rockets. This danger can be minimized if the tank is carried in the boat while the diver works off a long hose between the first and second stage of the regulator. Another option is to use the minature air supplies that hold 2-5 minutes worth of air. They are less apt to get caught in the current and hence are less dangerous. They are also easily reloaded by a normal tank on shore. The fish I have observed were very sensitive to exhaust bubbles and appeared to exhibit flight behavior when I exhaled.

Finally, equipment should not only help in prolonging diving time and quality of observations, but should also be colored and patterned to be inconspicuous. I have gone so far as to remove the red stripe from around the tip of the snorkel because I observed it affecting steelhead smolt behavior.

MEASURING MICROHABITAT

Some of the techniques discussed are not limited to large, fast streams. Since swift-water techniques are extensions of "normal" microhabitat data acquisition procedures, they will be briefly discussed.

Microhabitat study teams may be as few as two or as many as seven persons, depending on the situation and conditions. Teams of two consist of an observer and a meter operator/data recorder. When the water temperature is cold, I increase the team size to three (observer, meter operator, data recorder) and have the team members rotate roles frequently so that the observer does not become chilled. Under these conditions, I generally rotate every half hour to an hour of diving time. Once chilled, an observer is through for the day because he is usually suffering from mild hypothermia. Early signs of hypothermia are lack of decisiveness and short-term memory loss. In addition to being a dangerous situation, an observer experiencing this condition won't produce reliable data.

The goal of microhabitat use surveys is to observe fish behaving normally. Surveys that move upstream tend to be more effective because fish normally face upstream and the divers approach them from behind. This allows the diver more opportunity to detect the fish, identify the species, estimate the size, and determine its relative position in the water column before the fish reacts to the observer. Further, I believe that these are all the data for which the observer should be responsible. The remainder can be collected by the meter operator or the data recorder. By keeping the demands on the observer simple, more time can be spent locating fish and increasing the number of observations. Finally, team members must key on the observer. Fewer fish are spooked because the observer controls the team's movement.

Fish identification is a primary and difficult task for the observer. Many existing keys are useless for microhabitat work because they generally rely on subtle meristic characters that are not visually apparent. Fry stages of salmonids and cyprinids are especially difficult to differentiate. Prior to fielding your team, develop field guides with field marks for all fish and life stages of interest. Field check your field guides for accuracy.

Another problem observers encounter is accurately determining fish and substrate sizes. Water magnifies objects by approximately one-third, and it is easy to overestimate sizes. I have found it useful to compare the fish to background elements or reference objects and measure the objects to determine fish size. Observers should carry 6-inch rulers or other measuring devices.

I prefer electromagnetic current meters for microhabitat work because they record streamflow directionally and can measure stream velocities in cobble, rootwad jungles, or undercut banks where a cup meter can't. Electromagnetic current meters, however, have potential problems. They are delicate instruments susceptible to damage if dropped or submerged. They do not measure air-entrained water velocities reliably, and they are ineffective near strong electrical fields, e.g., beneath high-voltage power lines or downstream of hydroelectric power generators. [It is also difficult to obtain a good time-averaged velocity with these meters in pulsing water--eds.]

I prefer to use top setting wading rods with the current meters, since they are easier and faster to use and more precise than boat suspension systems. When stream depth exceeds the capacity of a 1-m rod, I use a 2-m rod. When it is necessary to use a boat and suspension system, data acquisition rate plummets because boat maneuvering and team size increases, generally demanding more time and coordination. I use Price AA current meters with a 75-lb sounding weight on a suspension system. Stream current in deep, fast streams exerts enormous pressure on the sensor bulb at the cord connection point of electromagnetic meters, creating a strong potential for breakdown. In addition, there is no way to use a reel for the electromagnetic meter cord. Cup meters measure air-entrained water more effectively than do electromagnetic meters.

I use similar techniques to measure microhabitat availability so that I can learn not only what the fish use, but also what they avoid and prefer.

SWIFT-WATER TECHNIQUE

Making habitat use observations in water too swift for swimming poses special problems. The method I use in streams too swift for swimming is generally described by Bovee (1986). Essentially, the method consists of observers using rock climbing rope ascenders to move upstream along polypropylene ropes suspended from a static line across the stream (Figure 1). Ascenders are cam brakes that allow the divers to climb the polypropylene rope inch-worm fashion. The static line is anchored upstream of the sampling site. From this line, a 1/2-inch polypropylene rope is tied. The ropes may be placed anywhere along the static line, covering the entire stream. I used this technique with 300-ft ascending lines on the Tuolumne River, California. This length worked well, but should not be considered a maximum length.

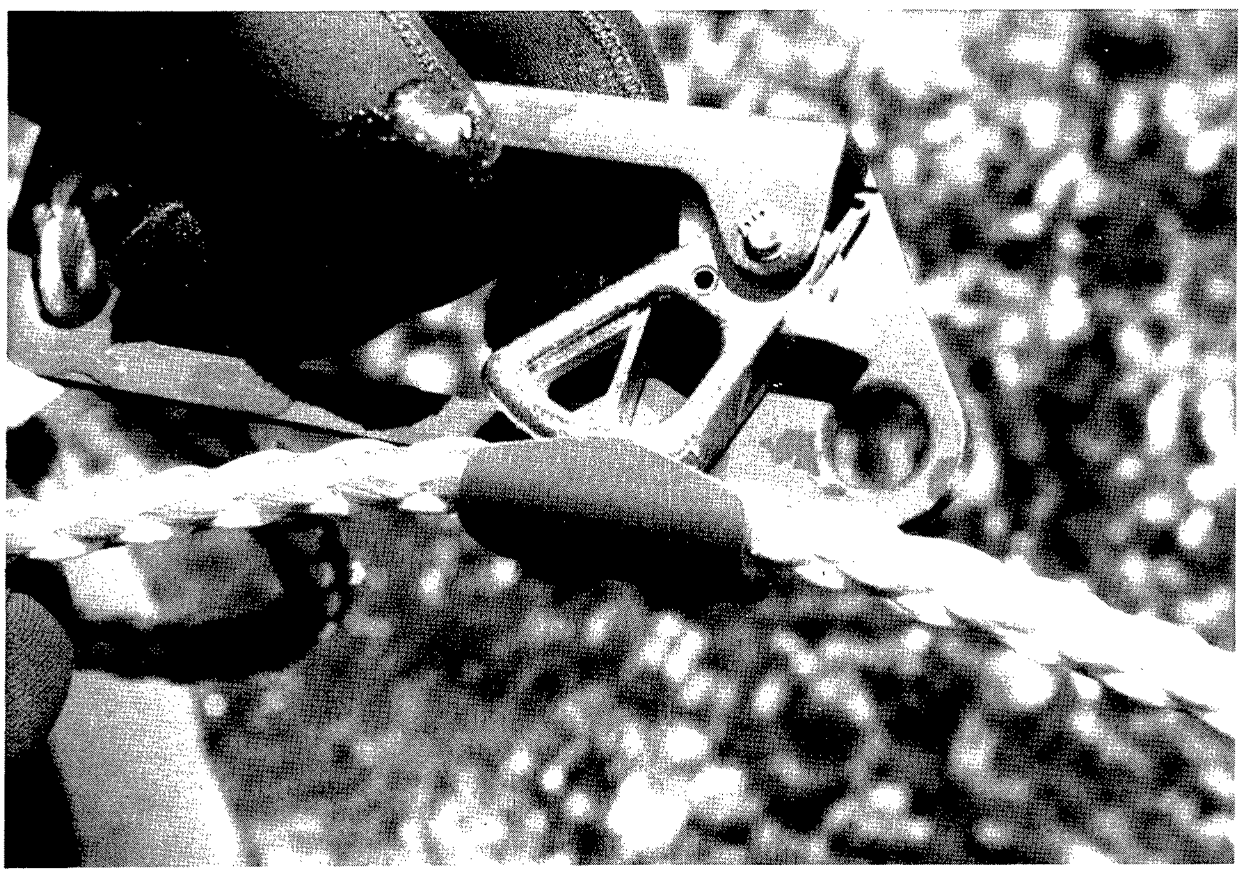

Figure 1. Insertion of a drop line into a mountaineering ascender. Note the cam brake in the center of the ascender, which allows the rope to be pulled through in only one direction. (Photo by K. Bovee.)

Initially, divers ascended the polypropylene rope using a single Gibbs Ascender with a loop of nylon webbing for a handle. This method was tiring to the diver, however, because he had to constantly work against the current, and it was inefficient because the diver used only one ascender. I have found that using a rock-climber's chest harness with two ascenders attached by means of 1-inch spiral webbing to be more effective (Figure 2). I have also found ascenders with handles, such as Jumars, to be easier to use with diving gloves on. The harness makes it unnecessary for the diver to hang on to the rope, thus conserving strength and energy when the diver is motionless looking for fish. The chest harness is equipped with a quick-release buckle for use in an emergency. Although not essential, I have found that fins help stabilize and maintain orientation while suspended from ropes.

My techniques differ somewhat from Bovee's (1986), however, in terms of improved effectiveness and safety. Bovee (1986) suggests using 1/8-inch aircraft cable for the static line. I recommend using 7/16-inch static Kermantle rope (rock climbing rope) instead. Kermantle rope has several advantages over cable: (1) aircraft cable is dangerous. The static line is usually tightened from each bank using hand winches (come-alongs). If a cable's tensile strength is exceeded, broken strands generally fray into hooks and the stored energy within the tightly suspended cable causes it to whip away from the break point and toward each anchor point, potentially striking bankside personnel; (2) aircraft cable is easily kinked, which reduces its tensile strength and increases its breakage potential; (3) once broken, cable must be spliced, requiring specialized equipment; (4) aircraft cable is not readily available from local stores, so down time due to broken cables will most likely be prolonged; and (5) cable weight and inflexibility make aircraft cable difficult to transport and handle, particularly when rigging it across the stream. In contrast, Kermantle rope does not store energy under tension nor fray if broken, making it comparably much safer to use. Kinking does not reduce tensile strength. If cut, it can be spliced or tied and used until a replacement arrives. Climbing rope is available at most outdoor recreation shops. Climbing rope is lighter and more flexible than aircraft cable and is easier and safer to transport and use. In addition, climbing rope is also stronger by weight and about half as expensive by length than aircraft cable.

NAUI and PADI warn inexperienced SCUBA divers to avoid ropes in water because of the rope's tendency to entangle the diver. However, with training and reasonable precautions, ropes may be safely used in streams. Swift water tends to straighten rope, negating danger of entanglement. In addition, I have found the following precautions reduce the danger. Anchor the rope suspension system well above the water's surface (Figure 3). This minimizes the tendency of streamflow to submerge the attached diver. Attach the static line well upstream of the study area and use long ascending lines. Divers on long lines tend to be "pushed" to the surface by stream velocities (Figure 4). Lastly, use polypropylene lines for ascending lines because these lines float.

Generally, if the observer cannot swim upstream, the meter operator will not be able to wade, making boat work necessary. For microhabitat use observations, I have tried two different observer-to-boat configurations. The first is simply to attach the diver to the rope that suspends the boat. Lateral movement of the boat is controlled by personnel on the bank, and up-

Figure 2. Diver equipped with chest and hip harness. Note the four-point connection and location of the carabiner/ascender. This method of connection prevents excessive pull on the corners of the attachment. (Photo by K. Bovee.)

and downstream movement is controlled by boat personnel (Figure 5). For a more detailed explanation of this suspension system and its procedures, see Li (Unpub. ms.). The diver directs movement of the boat with hand signals. The second configuration is to establish separate static line systems for the boat and the diver. I found the second configuration to be more effective. It

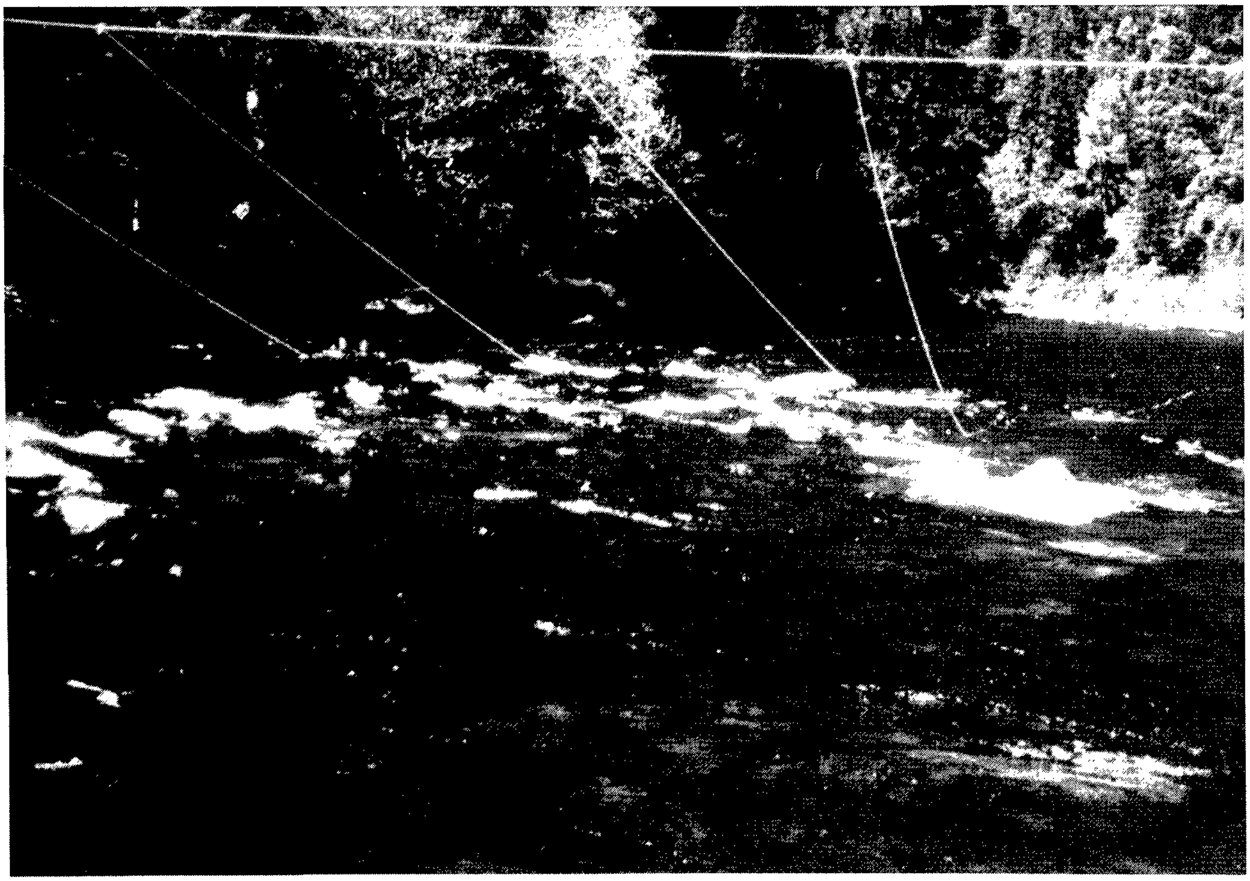

Figure 3. Static line with four drop lines deployed across river. Note the height of the static line above the water surface. (Photo by S.K. Li.)

allows the observer to find fish more rapidly and is less demanding on boat and bankside personnel. I typically use seven persons when sampling large streams with a boat: one observer, one meter operator, one oars operator, and four bankside personnel to move the boat.

The use of the techniques I have described will enable biologists to survey areas that were previously thought to be unsafe and impossible to sample. However, selection of where and how to conduct the survey requires careful planning, training, and special considerations for the safety of the diving personnel. Survey reaches should be selected upstream of still-water areas, which will provide divers a refuge or an easy exit in the event of an emergency. Placing a survey immediately above a falls would be folly. I recommend a training course by certified search and rescue instructors to properly learn the use of rope systems and swift-water rescue. All personnel must be trained to recognize symptoms of hypothermia and should have training in swift-water rescue, first aid--especially cardiopulmonary resuscitation (CPR), and swift-water swimming techniques.

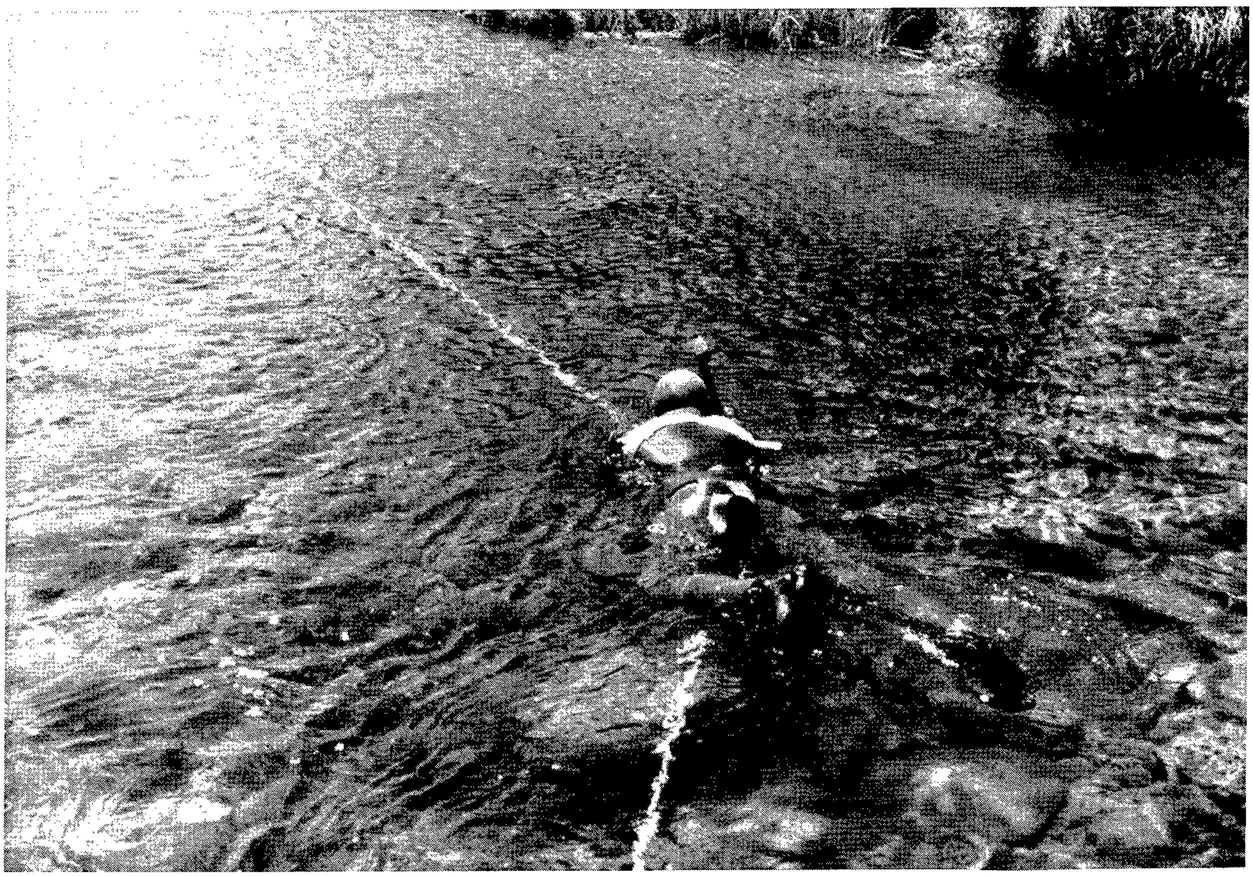

Figure 4. Diver "on line" ascending a drop line. (Photo by K. Bovee.)

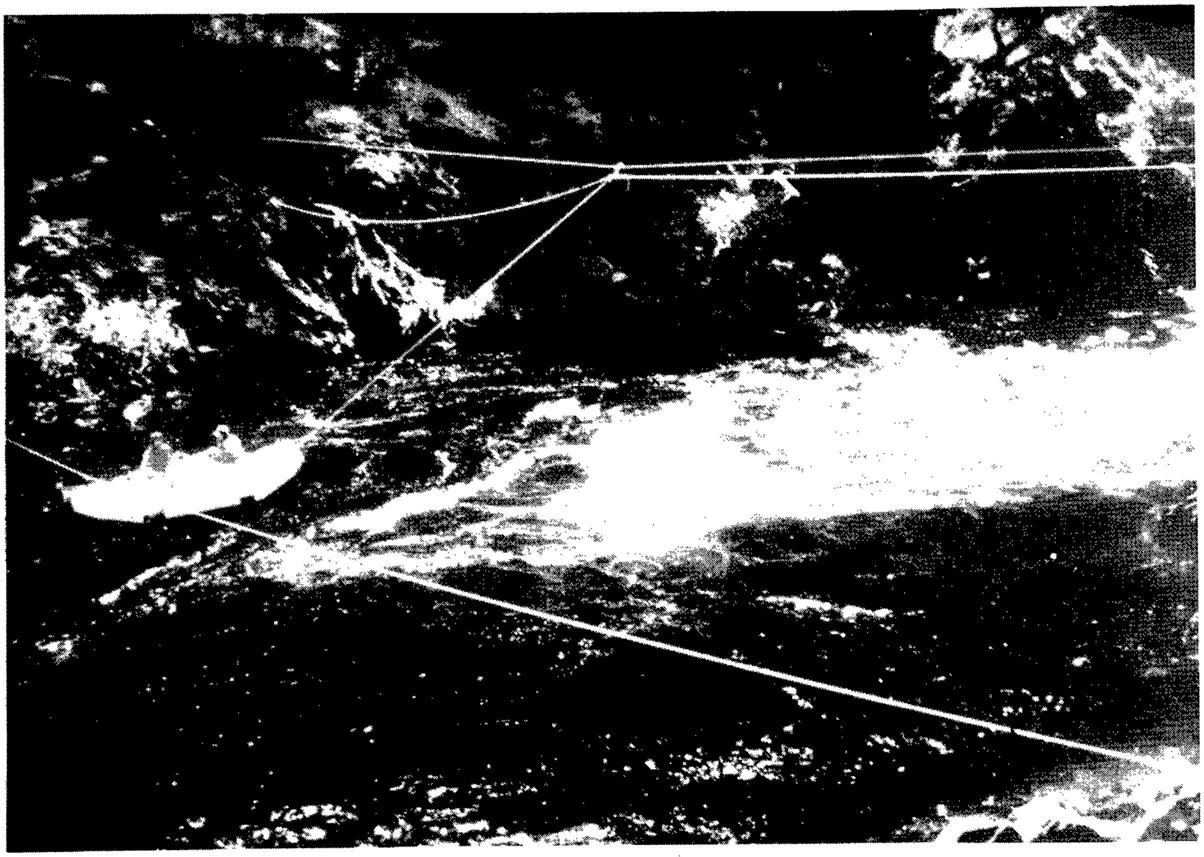

Figure 5. Raft with stream gaging equipment attached to rope suspension system. (Photo by S.K. Li.)

ACKNOWLEDGMENTS

Mr. Gary E. Smith, California Department of Fish and Game, critically reviewed this manuscript and vastly improved its content.

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QUESTION AND ANSWER SESSION

Stacy Li

Li: Several items were not mentioned in this presentation. (1) This is still a limited technique. The visibility has to be good because the diver will be on the surface. This means you need visibility at least from surface to stream bottom. In very deep water, the angle to see the fish decreases unless the water is very clear. (2) The observers must have the ability to recognize fish "on the fly." Often, the fish will not hold still long enough for a detailed examination. If you are dealing with small fish or a species that is unfamiliar to you, I suggest that you catch some of them, put them in an aquarium, and allow the divers time to familiarize themselves with the characteristics and behavior of the fish. (3) If you are dealing with a species like brown trout that like to get into the interstitial spaces between rocks, this technique may not work. (4) I haven't figured out how to make the static line/drop line system work around a corner. This essentially limits the technique to straight sections of a river. (5) You are responsible for the safety of people who are relying on you not to get them into a dangerous situation. Make sure that they're in an area where they can get downstream and get out safely. Everyone on the field crew should be able to recognize early symptoms of hypothermia, and they all should be trained in CPR. I recommend that if you get into rope work, have competent search and rescue personnel show you how to do it. The techniques I showed you are just the beginning. You can do much more than that.

Cressey: What mechanism did you use to raise and lower the 75-lb bomb (sounding weight) that you were using off the raft?

Li: I was using a Leupold-Stevens suspension reel. Even the smallest women on the study team were able to raise and lower the 75-lb bomb without too much trouble. There was little difference in the effort required to raise and lower a 50- or 75-lb bomb, and the larger weight was deflected less by the current. The only drawback to a 75-lb piece of lead is that it costs about $400.

Hanson: What came to my mind as you were giving your presentation is that many of the rivers I work in do not have very many good anchor locations.

Li: In terms of anchor technology, I advise you to consult with people involved in search and rescue. The reason they're so good is that their techniques have evolved from looking for bodies of people who have made serious mistakes. Following the techniques of the Tuolumne Search and Rescue team, we were able to anchor to a sheer granite ledge with pitons. You can also tie off ropes around large boulders if there aren't any trees. In the absence of large boulders, pitons can be used to make equalizing anchors. There's no magic to this, it's just a matter of figuring out how you can get a secure anchor that'll keep everybody safe using the available technology.

Hanson: To rephrase my question, do you feel like there were significantly large areas up the river that you couldn't sample for whatever reason?

Li: I wouldn't try to sample directly upstream of rapids that kayakers give names to. I suspect that given a little bit of work that SCUBA techniques would work with very experienced divers. However, I am leery of SCUBA in this situation, because if the tank hits a rock and breaks the valve on the first stage, the tank may explode or take off like a rocket. One way around this problem might be to extend the length of the hose on the second stage and put the tank on the boat platform. Movements between the raft, the diver, and the people on shore could be coordinated by hand signals. Another technique would be to have the diver immediately in front of the boat. The same thing would work using Hookah gear. A potential problem with a long hose is that the current will pull on the hose and could tug the mouthpiece out of the diver's mouth. An alternative might be the use of mini air supplies that have a couple of minutes of air. You can use that for short excursions and then recharge it from a "mother" tank when you come up. My fish didn't like bubbles at all, so I didn't spend much time tinkering around with SCUBA. When we exhaled, they took off.

Hilgert: I'm not sure that everyone north of California agrees with your conclusion about dry suits.

Li: I'm not saying dry suits are bad. I'm saying that wet suits have gotten a bad reputation because people buy them off the shelf and they get one that doesn't fit right. So, what they get is a suit that leaks like a sieve. The key to staying warm in a wet suit is that you just want one volume of water to warm up and once it's in there, you don't want it to get out. If it's really too cold, I'm not adverse to dry suits, but they are more expensive. In our little business, that's a real consideration.

Hilgert: One way to protect your investment is to get a nylon overall bib and wear it over your dry suit.

Payne: Were you able to place meaningful hydraulic transects in some of the same places you were taking your microhabitat measurements?

Li: Yes.

Payne: No problem with different water surface elevations across the transects in turbulent water?

Li: We had a considerable variation on the water surface elevation across the transect. Our solution was to take many measurments, sometimes as many as 20 measurements across each transect.

Hilgert: Many high gradient streams will have perched water surface elevations. We have run into situations where we've found four or five of these perched water surface elevations on a transect.

Bovee: Currently, there is no way in the program to handle stacked water surface elevations, but I may have a solution to the problem of surging water

surface elevations. One thing that might improve the measurement of water surface elevation is to use a little portable stilling well. Take a piece of approximately 6-inch PVC pipe, cut slits in it (near the bottom), set it down into the water and then take the water surface elevations inside the pipe.

Li: Clear plexigless also works well for a portable stilling well. We use that to settle down water surfaces around our temporary stage gages.

Hampton: I am concerned with the suspension system that you're using to lower the sounding gear and current meter from your raft. The water velocity measurements taken underneath the raft may be affected by the presence of the raft directly overhead.

Li: As a matter of fact, the raft that I have now is a catamaran, so the measurements I take are not affected by any surface drag immediately overhead.

Question from the floor: All of this equipment must be very expensive. Do you know how much you have invested?

Li: Let me figure the cost for the whole thing. I had a crew of 20 and they each needed wet suits, fins, snorkels, and masks. This cost about $300 to outfit each crew member.

Question from the floor: You didn't have them all in the water at the same time, did you?

Li: All 20 were not in the water at the same time, because of the way we rotated our personnel. I think we have probably spent about $30,000 on equipment. Those rafts cost about $2,400 each and the frames were about $500. When you are buying rope, don't just buy enough to go from bank to bank. You'll need at least 50 percent more. Buy lots of carabiners and cam brake ascenders. Once you learn how to use them, you can do some marvelous things with them. They will get you into places that you never thought you could go.

Cheslak: How much of the population do you think went unobserved because of places that you could not get in to?

Li: The Tuolumne is fairly steep, with riffles that were more properly described as rapids. Hydraulically, they were still riffles, but about an order of magnitude larger than what we normally would call a riffle. Of the ones we could get in to, or immediately downstream from, we didn't see fish of any sort. The fish would be downstream above the pool until you got almost to the tail of the next thing down. Most of my people were certified divers with masters ratings. I would have them go down and move along the bottom and look among the rocks, and they're not there.

Aceituno: What were some of the highest velocities that your divers could effectively work in?

Li: We didn't really test the maximum velocity in which we could work, but we did work in velocities up to about five feet per second. With only one ascender apiece, it took the divers a long time to work through fast water areas. It really increases the efficiency to use two ascenders. Also, in

faster water they tended to lose body heat faster, so we rotated our divers more frequently.

Barrett: One thing you might try is to pour hot water into the wet suit prior to the dive. That way you don't lose any body heat trying to warm up that initial volume of water.

Li: Yes, that would help, and it also helps to have the divers load up on carbohydrates and hot food before they get into their wet suits.

Leonard: You've identified the major entry of water as being around the neck and you've recommended a high collar. I was wondering if you tried a hooded vest underneath the wet suit jacket, with another hood on top of that. The second hood stays over the outside of the wet suit collar and is held down with velcro.

Li: That's a good idea, but there is one thing to watch out for. There is a story that Gary (Smith) tried something like that. He got in the slack water behind a boulder, but when he looked around the side of the boulder the high velocity water caught the hood and expanded it like a sea anchor. The whole suit filled up with ice cold water.

Bovee: How did you orchestrate the movements between the diver and the boat? After a diver spotted a fish, did he just wait there on the line until a boat got there? Or did he direct the boat over to where he saw the fish? Exactly how did that work?

Li: The technique I was most comfortable with was to have the diver either immediately behind the boat or immediately in front of the boat. The fish did not appear to care whether the boat was there or not, and I didn't have to release any additional rope. The diver would identify the species, estimate its size and its distance from the bottom. The people in the boat would make the depth and velocity measurements, and the diver would go off and look for another fish. The divers had the responsibility of describing the substrate, and they carried reference scales to compensate for the 30 percent magnification. They also had metric rules with the Wentworth scale etched on it.

Smith: Did you try to have your diver put down markers at various fish locations?

Li: In this situation, I did not. The observers have to be as inconspicuous as possible. Using a system where the diver leaves markers at points to be measured by another crew, the diver might be very inconspicuous, but the crew following behind may create quite a disturbance. Sound travels seven times faster under water and it moves upstream as well as downstream. The use of markers might have improved our efficiency, but I sacrificed frequency of observations for quality.

Puttman: We, in Colorado, have never tried the kind of techniques that you've described, but I'm concerned about getting the boat to exactly the right spot where the fish were observed.

Li: This is one of the reasons it's important to keep your observers fresh. If the diver can't tell if the boat is in the right place, that may be a sign that he is going through early stages of hypothermia. It is the diver's responsibility to direct the boat to exactly the right spot.

Campbell: Once the diver has spotted a fish, how long does it take the boat crew to position themselves to take the measurements?

Li: To get to the spot, less than 10 seconds. The rest of the measurment can usually be taken in less than five minutes depending on where they are, how deep the water is, and so forth.

Campbell: Are the diver and the raft both on the same line at that time?

Li: The diver can either be holding on upstream or tethered to the raft and the two moved as a unit. In that case, the diver just waits until the measurements are made and then they go off hunting again. The other way is more flexible, but you need a lot more rope. Without being tethered to the raft, the diver can climb different ropes. The observer can actually swim from one rope to another rope.

Bovee: Let me see if I understand this. You have the observer stay on station until the boat gets there?

Li: In my first example, think of it as a diver-boat team. In this case the diver would stay on station until all the measurements were taken. Where the diver operates independently on a multiple rope system, he directs the boat to the spot by staying stationary until it gets there. Once he gets the boat there, tells the data recorder the species, life stage, and the other information, then the diver can either take off up the same rope or actually swing across, detach, and attach to a different rope.

Payne: How many people does it take to support a diver in an operation like this?

Li: It's a function of discharge. On the Tuolumne River, where the discharge was running over 3,000 cfs, we had seven people on the bank and two in the boat. When the flow went down to 1,700 cfs, we had a bank-side crew of three on one side, one on the other side, and two in the boat. Collecting this kind of data is technically challenging, so you will need a lot of people. It's not a question whether the data can be collected or not. It's just that each data point is quite expensive. To do it right and do it safely, you are going to need more people.

Bovee: How many divers can the boat handle at a time? I mean, if you have several divers out there and one of them spots a fish, then has to wait half an hour for the boat to get to him, he's going to be cold and tired.

Li: It works out quite well with a harness because the diver isn't expending that much energy. I would say you could work two divers easily, and if you had a very efficient boat crew, you could probably have three divers per boat. That would certainly increase efficiency, but your data recorder would have

to be very sharp. You should keep separate data sheets for each of the divers, in case someone is having problems. If there are any questions about the quality of the data from one of the divers, perhaps due to hypothermia or over exertion, then those data can be safely culled without losing the rest of the data.

TECHNIQUES USED TO OBTAIN HABITAT PREFERENCES DATA ON HOLDING-STAGE ADULT SPRING CHINOOK SALMON IN A CLEAR STREAM

by

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INTRODUCTION

Among the anadromous species of salmon (Oncorhynchus spp.) and the steelhead trout (Salmo gairdneri) there are two races that enter an adult holding stage soon after entering freshwater streams: the spring chinook salmon and the summer steelhead trout. An adult spring chinook typically migrates from the ocean during spring, ascends a cold stream until it finds a suitable place to rest, and then holds there several weeks while it matures, before entering the spawning stage (Royal 1972). The amount of suitable holding habitat has declined over the years, due to man's activities. Protection of such holding habitat has become increasingly important to resource agencies. In 1984, the U.S. Fish and Wildlife Service decided to study holding spring chinook and to develop holding-habitat preference criteria. Field work to develop these criteria was begun by the Fisheries Assistance Office, Olympia, Washington, in 1984, and was completed in 1985 (Wampler 1986). This paper describes the field techniques used to gather these data.

STUDY AREA

We made observations of holding spring chinook in the Wind River, a tributary to the lower Columbia River, in southwestern Washington (Figure 1). Wind River water clarity, abundance of holding spring chinook, and diversity of instream habitat types provided some of the prerequisites for a suitable preference criteria study. The Wind River remains clear during most of the spring and summer holding period. The Carson National Fish Hatchery (CNFH), located at river mile 17.4, supports the hatchery portion of the spring chinook run. A wild portion also exists, having developed from spawners that strayed from the hatchery. The Wind River spring chinook run was protected from fishing, which enhanced our opportunity to find a sufficient number of

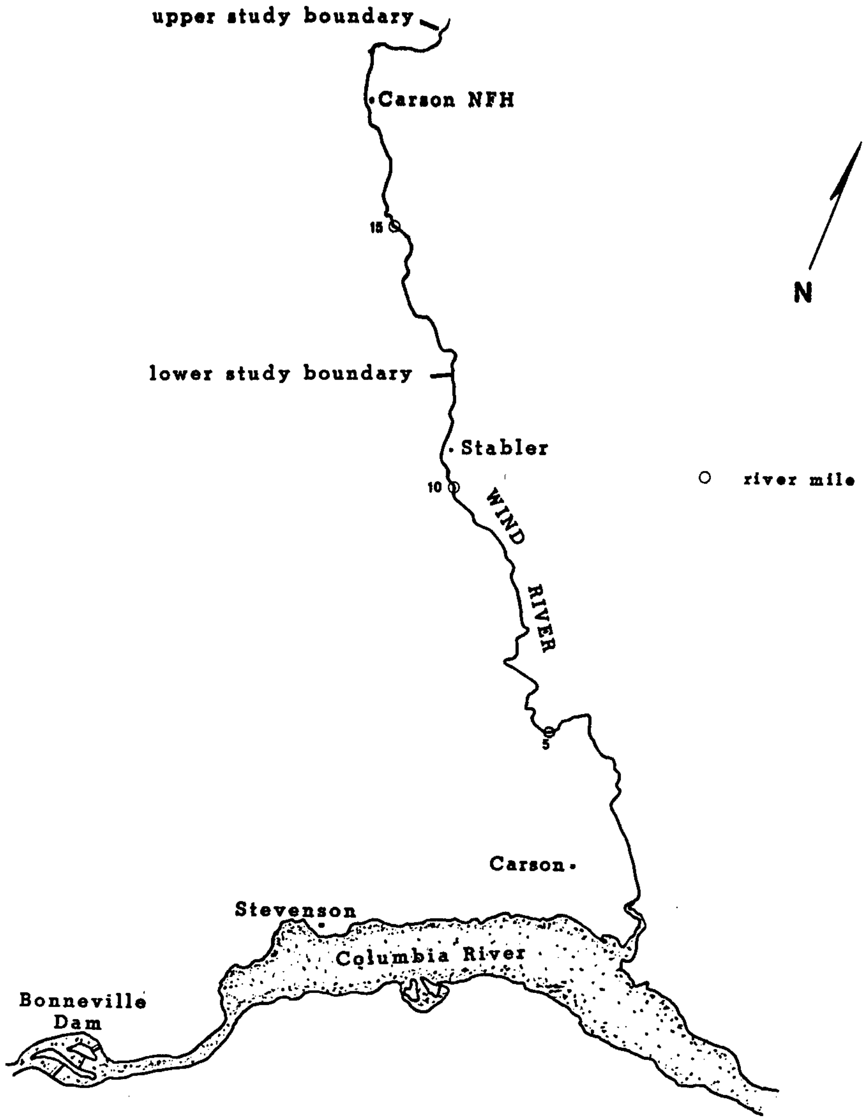

Figure 1. Location of the Wind River and the study area.

unharassed holding fish. In addition, access to the river was generally good upstream of river mile 10.

METHODS

Through discussions with the CNFH staff and a preliminary snorkel survey, I determined that most holding fish were located in the upper river valley, between river miles 12 and 19. This reach was characterized by generally

moderate gradient, some meandering, gravel to boulder substrate, a good pool to riffle ratio, and scattered sections offering good protective cover for fish. I concluded that our data collections should be confined within this reach. I excluded from data collection the river section immediately downstream of the CNFH because of the possibility of introducing data bias from unusually high concentrations of spring chinook there.

The field procedure used was largely guided by recommendations of staff at the Instream Flow and Aquatic Systems Group (IFG) and related material in IFG publications (Bovee and Cochnauer 1977; Bovee 1982). Baldrige and Amos (1981) described the general method I employed to analyze field data and to develop preference curves. Collection of field data fell into two principal categories, habitat utilization data and habitat availability data.

UTILIZATION DATA COLLECTION

Data collection to develop a utilization function generally followed guidelines for gathering probability-of-use (Bovee and Cochnauer 1977) or habitat utilization curve data (P. Nelson, unpublished). A utilization function is derived from a frequency analysis of microhabitat physical and hydraulic characteristics measured at point locations of target fish (Bovee 1986).

Based on previous experience and discussions with biologists who had observed holding adult spring chinook, I concluded that observations must be gathered by snorkeling in an upstream direction. Bovee (1986) suggests that snorkeling in an upstream direction provides equipment simplicity and a preferred sampling strategy. During preliminary snorkeling, I concluded that this technique would work satisfactorily.

A number of factors shaped the utilization sampling design. It became obvious that successful fish observation would require that the snorkeler approach any potential holding location with great care to minimize his presence and visibility to fish. An observation would be unuseable if a fish could not be observed over a period long enough to assure that it was exhibiting holding behavior. My criteria to confirm that a fish was holding were as follows: the fish must not leave its original location; the fish must be an adult spring chinook showing no signs of obvious ill health; and the fish must not have been observed previously during the sampling day, either as a recorded observation or as a frightened fish in flight.

Sampling design was also a factor of holding-fish availability and sample size. Assuming that the minimum required sample size was 200 utilization observations, I expected difficulty in arriving at that goal. Time and project funding were limited. Holding-fish locations presumably would be scattered, thus requiring considerable time per collection of successful observation. Given these sample design considerations, I concluded that the only practical design was to sample throughout the utilization reach (miles 12 to 19) and to record an observation for any fish that met my criteria for holding behavior.

We gathered utilization data within a different segment of the utilization reach on each sampling day. This approach eliminated the risk of repeating

measurement of a particular fish at the same location. I assumed that if a fish was remeasured at a new location in another river segment, then it was useable data.

OBSERVATION PROCEDURE

Fitted with full wet suit, mask and snorkel, and felt-soled canvas shoes, one person cautiously moved upstream until an adult spring chinook was located. At that point, the following tasks were performed: (1) the fish (one or more) was observed from a distance to determine if it was a holding spring chinook, i.e., stationary, and its exact position in relation to the stream bed and the water column; (2) once a fish was determined to be holding, and its location data were relayed to an assistant on the stream bank, the snorkeler moved to the point of location to gather additional information; (3) total depth and depth of the fish (nose depth) were read from a top-setting wading rod placed at the stream bed point over which the fish's nose had been; (4) flow velocities of the mean water column and at nose depth were measured over the point of fish location (using either a rod-mounted Swoffer-adapted Price AA or Pygmy current meter, or a rod-mounted flow digitizer with a current meter); (5) the dominant substrate category and its percent, and the subdominant substrate category at the point of fish location were recorded (particle size categories were developed by an interagency substrate committee (Washington Department of Fisheries 1983); and (6) presence or absence and category of overhead protective cover, within about four feet of the point of location, were recorded. Any appropriate comments regarding a completed observation were also recorded. At the end of each day, data were reviewed for accuracy and completeness. A tally of actual hours spent working in the river was also maintained.

A sample size of 150 to 200 observations is usually sufficient to develop satisfactory suitability curves, but a statistical test should provide the final guidance as to sample size (Bovee 1986). Following the completion of data collection in 1984, I tested the data for sample size (Snedecor and Cochran 1972). We had collected 129 observations. At the 95% probability level the test indicated that larger samples were required for the continuous variables, i.e., total depth, fish nose depth, mean column velocity, and velocity at nose depth. As a result, one additional year (1985) to collect fish observations was required. We were unable to collect additional data beyond 1985. Following advice regarding data pooling, offered by the IFG staff, I limited our sampling effort during 1985 to the level exerted during 1984. This was done to avoid biasing the pooled utilization data.

Some additional measurements were recorded in the second year. Water temperature was recorded occasionally during the work period, but not during all sampling days. Presence or absence of shade at a fish location was recorded for each fish observation.

Mean size of observed fish would be of interest to anyone that might later use the study results. We could distinguish between adults and jacks (i.e., precocious males), but we did not attempt to measure fish lengths, in order to minimize fish harassment. It was reasonable to assume that mean size of observed fish would not vary significantly from that of fish taken later at

CNFH during the annual egg collection and fertilization. Therefore, data on fish size were obtained from CNFH.

AVAILABILITY DATA COLLECTION

After considering habitat availability sampling options suggested by the IFG staff, I chose to use the habitat mapping or proportional sampling approach (Bovee 1986). Given our available time, this appeared to be the most practical option.

Based on preliminary walking and snorkeling surveys in the utilization reach and use of maps and aerial photographs, I selected an availability sub-reach (AR). Habitat conditions in the AR appeared to represent the relative proportions of those conditions in the total utilization reach. The AR was located at about mile 16.3 and had a length of about 600 feet.

Development of the availability function required that I determine percent of AR surface area for any interval of a variable present during the period of utilization sampling. At the outset, I hoped to collect all required utilization observations during a period brief enough that no significant change would occur in river stage. I established a staff gage within the AR to monitor river stage. I used the gage to guide decisions on when to collect availability data. During the 1984 utilization sampling period, I concluded that only one availability data set, collected midway through that period, was required. By this same procedure, I found it necessary to collect two additional availability data sets during the summer of 1985.

Each availability data set collected required about two days effort from a crew of two or three people. Data collection procedures employed within the AR generally followed standard procedures of the Instream Flow Incremental Methodology (IFIM) developed by the IFG. Ten transects, perpendicular to the direction of river flow, were established within the AR. Total depth, mean column velocity, substrate, and protective cover were measured at transect verticals to determine the total AR wetted surface area having specific values or codes of instream variables. Actual measurement procedures were identical to those used in utilization data collection.

One unexpected development arose from comparing the ranges of respective instream variables among utilization data with those among availability data. Development of the total depth preference ratio required that the relative proportion of all increments of total depth available to holding fish be accounted for in the calculations. Maximum water depth in the AR was not as great as at some locations where fish were observed in the utilization reach. It became obvious that those greater depths must be represented in the AR. To correct this, I devised a means of estimating the lineal proportion of the utilization reach that consisted of increments of total depth exceeding the maximum depth found in the AR. This task was accomplished by making map planimeter measurements on a composite set of aerial photographs of the utilization reach. I relied on my familiarity with the deepest sections of the utilization reach to mark these sections on the photographs. The correct proportion of surface area representing water depths greater than in the AR was then added to the calculated AR surface area for total depth. This added

area was divided equally among the increments of depth ranging between the maximum depth in the AR and the maximum depth observed anywhere in the utilization reach.

DATA ANALYSIS

Following is a brief explanation of my data analysis to help clarify objectives of the field techniques. I performed frequency analyses on the utilization data, for individual sampling periods and for the three combined sampling periods. I standardized all frequencies (Baldrige and Amos 1981). I then constructed utilization curves. The final utilization calculation was to determine the utilization functions, i.e., the percentages of all holding fish observed at respective variable value intervals and categories.

To derive comparable availability functions, I pooled data from the three availability data sets. For each data set, I mapped the AR surface area for variable value intervals and categories using standard IFIM procedures. I then tabulated the mapped data and calculated respective percentages of total available habitat per value interval or category. These percentages represented the availability functions.

RESULTS AND DISUSSION

SNORKELING

Snorkeling in an upstream direction to gather observations of exact holding locations worked well. The snorkeler was able to move upstream by pulling on rocks or wood objects on the stream bed or on submerged logs and limbs extending from the bank. This technique was normally silent. We thereby avoided the surface disturbance that typically occurs when using swim fins. Occasionally, the snorkeler encountered stronger currents, which required walking against the current. Felt-soled shoes greatly reduced the difficulty of this task. There was almost never any need for the snorkeler to submerge for more than a few seconds. The maximum depth encountered in any pool was about 15 feet. In deep water, we found it necessary to wear weights to aid in submerging to depths where fish might be hidden from view. In consideration of our relative snorkeling success, given the maximum pool depths and excellent water clarity, it appeared that the use of SCUBA was unnecessary for this study.

Excellent water clarity and midmorning to late afternoon daylight generally provided adequate fish viewing conditions. Typically, water clarity permitted the snorkeler to see stream bed detail in the deepest pools. Fish were usually sighted before they appeared to detect the snorkeler's presence, and they normally tolerated the snorkeler within the distance required to secure data, even after detection. Some fish refused to leave their holding location despite the immediate presence of the snorkeler and sampling equipment; but some fish swam rapidly away.

HOLDING BEHAVIOR

The following description of observed holding behavior is included to further define the type of snorkeling effort required. We found holding-fish behavior to be generally consistent within the utilization reach. Certain stream habitat types appeared to attract holding fish, regardless of river mile. Deep pools or glides with some form of overhead cover often contained concentrations of holding fish. However, one form or another of overhead cover frequently sheltered one or more holding fish when located in more shallow water.

Early in the process of collecting utilization data, I observed that holding fish frequently used cavities formed under large boulders or stream banks. If possible, they would position themselves entirely under an object so that they were not visible except to the snorkeler viewing them from the same depth. Fish holding under such objects were observed facing in all possible directions. On several occasions, such fish were observed respiring at a depressed rate. When touched by the snorkeler these fish did not react normally, but instead appeared to be quite lethargic. Similar behavior has been observed among holding summer steelhead trout (J. Cederholm, Washington Department of Natural Resources; pers. comm.).

Fish that appear to be holding that also show signs of ill health should not be included among recorded observations. More than once we encountered spring chinook with bad fungus infections whose behavior was entirely altered from that of normal fish. For example, one such fish had no fear of the snorkeler and appeared to be curious rather than alarmed.

The activity level of holding spring chinook appeared to increase with increased presence of other holding fish. This was most apparent in the larger, deeper pools. One or two fish holding alone usually remained stationary until the snorkeler moved close to take measurements; however, in larger groups fish usually began moving about the pool, and individuals appeared to react to the movements of other fish.

It appeared that holding fish sought out the deepest pools available. Deep stream segments, when they existed, appeared to attract and provide suitable holding for the greatest number of fish. More holding fish per stream surface area in the Wind River could always be found in such stream segments.

DATA COLLECTION

We developed a utilization sampling strategy that made maximum use of a two-person crew. The snorkeler carried nothing as he searched for holding fish. He worked more safely with his hands free and was able to maintain greater efficiency and alertness. Meanwhile, the assistant provided total support, i.e., recording all data, carrying all required equipment, substituting when the snorkeler became too cold to continue, and always available to render emergency help. This work structure freed the snorkeler from the complexities and difficulty of recording data (Bovee 1986). Another

advantage of the small crew was better continuity in our fish observations and variable measurement techniques.

While the use of markers for later relocation of fish positions has been recommended (Bovee 1986), we experienced no difficulty without their use. The snorkeler moved onto each holding location almost immediately after observing a fish and had no difficulty relocating the correct point over the stream bed.

Proportional sampling to determine availability provided certain advantages. Correct procedures for habitat mapping have been well documented (Trihey and Wegner 1981). Familiarity with those procedures improved our efficiency in data collection. By being able to concentrate all our attention on the mapping during three brief periods, we benefitted from greater effectiveness during both mapping and gathering fish observations. The concept of pooling together the additive mapping data (Bovee 1986) was relatively easy to grasp, and calculations, even by hand, were not too demanding.

The need for caution in selecting a suitable proportional mapping site (Bovee 1986) was demonstrated in this study. Overlooking the comparability of the full range of values for any one variable can potentially invalidate, or at least weaken, the respective preference function. I found a way to correct for my oversight, i.e., adjusting for missing maximum depths in the AR; however, this might not always be possible.

APPLICATIONS

Application of the techniques described above obviously must be limited to certain streams and objectives. At some level of increased turbidity, snorkeling becomes impractical. In streams that are clear enough, this technique should be considered first for studies to observe adult holding salmonids. It should work particularly well for holding spring chinook or steelhead trout. If preference criteria development is the objective of a study proposed for a single stream, the researcher should be reasonably confident that the population of the target species is large enough to allow success. Ideally, observations should be secured in a brief enough period to avoid the need to collect numerous sets of availability data.

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QUESTION AND ANSWER SESSION

Phil Wampler

Li: Were you saying that you collected your availability data on separate days, assuming that the availability remained constant over a period of time?

Wampler: I tried to relate availability data sets to general periods of utilization, so I was using a staff gage as a guide. I more or less subjectively decided if I needed to get another data set, based on relative river stage.

Li: So you were taking both utilization and availability data at the same time?

Wampler: The activity that required most of our time was the collection of utilization data using a two-man team. When I determined that it was necessary to collect availability data, we stopped collecting utilization data and, with the help of one or two volunteers, began to collect availability data.

Li: What I thought you said is that you collected all utilization data one day and then all availability data the next day.

Wampler: No, the utilization sampling period was spread over several weeks, whereas the availability sampling period lasted only one or two days.

Brad Caldwell: Now that you've finished gathering your data using a wet suit, have you converted over to a dry suit?

Wampler: I now have a dry suit, but I think if I had to do the study over again, I would be tempted to use the wet suit. However, it was very cold at times. The lowest temperature was about 50 degrees and during the hottest time of the year, it might have reached 65.

Caldwell: Did you determine that there was much difference between the holding locations of jacks and adults?

Wampler: I tended to ignore the jacks, but they tended to be found in the same places as holding adults.

Caldwell: Would there be a higher preference for overhead depth cover if you had used depth as a cover type?

Wampler: I didn't look at depth as a form of overhead cover, but as I pointed out, there was an obvious relationship between flow and depth in the presence of holding adults.

Campbell: You said you collected about 130 samples and you wanted to see if you could collect some more. Did you ever try to develop preference curves based on those 130 samples and then compare those curves with preference curves developed from a larger data base?

Wampler: I haven't done that.

Campbell: What was your final sample size?

Wampler: 537.

Bruya: When you were taking temperatures during the second year, did you take surface water temperatures and also temperatures from the bottoms of the pools where the fish were holding?

Wampler: No, we didn't. This past summer I was involved in a project on the South Fork Nooksack River, where Kent Doughty was doing a thorough temperature analysis. There are a lot of similarities between the South Fork Nooksack and the Wind River. He was looking at temperatures in the bottoms of the pools, as well as at the surface, and he found almost no difference. I think it's safe to assume that the same thing was occurring in the Wind River. It would have been a good thing to measure, but I didn't take the time to do it.

Payne: Did you notice any temperature difference when you were diving?

Wampler: There were places where it seemed a little colder, but nothing stands out in my memory, and I wasn't down there very long either.

Bovee: Did you or someone else say that you tended to find these fish more at the heads of the pools or the tail of the riffle than at the tail of the pool or the head of the riffle? Even though you would find the hydraulic conditions to be the same at both places, did the fish tend to be congregated near the head of the pool.

Wampler: No, I didn't say that. I wouldn't really say that they were really oriented towards one end of the pool or the other. There seems to be a much more definite relationship with proximity to cover. But, in the deeper pools the fish had a tendency not to stay directly under cover. They seemed to be more relaxed in deeper water.

Li: You were developing these criteria for holding fish, but what was your definition of holding and how could you tell if the fish were doing that?

Wampler: Basically, if I didn't see anything unusual happening, I counted the fish as a holding fish if it did not move. Normally, I would watch each fish for at least a couple of minutes. Sometimes it was for a little longer. It was really obvious when we saw some fish that were moving. If there was a fish that we weren't quite sure of, we would watch it for a longer time.

Li: How about fish that were possibly disturbed by your presence and moved after you had seen them?

Wampler: If I felt they were disturbed by my presence, I wouldn't count them.

Barrett: When you encountered groups of schooling fish, did you count individual fish or did you consider the school to be a single entity?

Wampler: I counted individual fish.

Leonard: I've dealt with some schooling fish and I think in a statistical sense you have to treat a school of a standard size as one, but you might also weight your calculations in terms of statistical differences. You may want to use a weighted mean for calculations to establish some of those microhabitat variables. You may even want to use a weighted mean based on the school size. The other thing is that we will often take a number of measurements, for example, rosefin shiners will often appear in schools of 5 to 150 or 200, and what we would occasionally do is to take one measurement on a regular basis for every 20 fish in the school so with a school of 150 fish in an area, you would end up taking maybe 5 to 7 measurements located within the cloud. We haven't really found anything that says which is the best way to treat schooling of fish.

Li: Following that same line of logic, it seems to me that we should be measuring the area occupied as well. For example, if we have an area this long (the size of this table), we should be making multiple measurements in that area to make sure that the microhabitat conditions are fairly uniform.

Barrett: My trouble with counting and these observations is that you have to count how many fish are using the same area.

Bovee: With respect to counting these little fish, how do duck counters do this? It just seems that some of these problem of counting numerous animals has already been solved.

Nelson: We used to count blackbirds. When you are dealing with flocks of millions, you would end up counting by hundreds.

Lifton: Ken, we counted over 400,000 salmon smolts, and generally we used "multibanked tally wackers," 1's, 5's, 10's, and 25's. Instead of counting, we approximated the number of fish in the groups. That was usually close enough.

Leonard: Here's another thing you can do if you're using underwater observation. If you have several people, you can force the school through a constriction. They flow through the constriction like an hour glass and can virtually be counted one at a time. If you are in a small stream, you can also force the school to separate. Then, when part of the school moves forward, the rest of the school will fill in behind them and you can count them as they go by a certain area.

WINTER FIELD METHODOLOGIES FOR DETERMINATION OF HABITAT UTILIZATION OF BROWN AND RAINBOW TROUT IN TWO COLORADO MOUNTAIN RIVERS

by

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INTRODUCTION

The Instream Flow Incremental Methodology (IFIM), developed by the Cooperative Instream Flow Group, U.S. Fish and Wildlife Service, is used to evaluate environmental changes in streams and rivers (Bovee 1986). This methodology uses hydraulic simulation modeling to predict the physical conditions of substrate, depth, and current velocity of a stream or river at various discharges, from which the amount of habitat available for the target species can be predicted over a range of discharges.

One major requirement of the IFIM is the need for suitability-of-use criteria for the target species for the three physical parameters. These "habitat criteria" are the link between the hydraulic simulations and the predicted habitat units, termed Weighted Usable Area (WUA). The accuracy and reliability of predicted WUA is directly related to the degree to which the habitat criteria reflect actual conditions. There are several sources of existing suitability-of-use criteria for salmonids, which were developed from both literature reviews and field studies (Bovee 1978; Raleigh et al. 1984a, b). The existing habitat criteria contain habitat utilization data for a wide range of values for each environmental parameter during all seasons. Moyle and Baltz (1985) and Bovee (1982) suggest that the existing habitat criteria be modified to more closely reflect the habitat utilization in a particular lotic system or at critical times of the year.

The target species for this study were rainbow (*Salmo gairdneri*) and brown trout (*S. trutta*). Several previous studies have demonstrated a seasonal change in salmonid behavior (Needham and Jones 1959). One response to winter conditions is decreased metabolism and corresponding reduced activity level.

Reimers (1957, 1963) found that trout were less active and fed less during winter than in the same streams during warmer months. He also found that trout were acclimated to the colder temperatures and appeared to feed on the available food items. However, food was less available in the winter than in summer. The slower metabolic rate during the winter months requires a lesser food intake to maintain the energy requirements of the fish.

Winter conditions may have effects on salmonid behavior other than decreased activity and feeding. Bjornn (1971) found that juvenile salmonids in Idaho streams entered the interstices between rubble substrate when stream temperatures were between 4-6 °C. This behavior was apparently to reduce energy expenditures. Bustard and Narver (1975) noted similar behavior in coho salmon and rainbow trout.

Because of apparent changes in salmonid behavior during winter months, it follows that habitat criteria will also be different during winter than during summer months. This study was conducted to describe the winter habitat requirements for rainbow and brown trout in Colorado streams.

The existing suitability-of-use criteria for rainbow and brown trout found in Raleigh et al. (1984a, b) seemed to have broad ranges of each physical parameter, with high suitability of use. As stated in these publications, the published habitat criteria are to be used as guidelines, and the actual criteria will vary according to geographical area. More specific data collected in the study area would represent actual conditions much better than the relatively generic published curves.

The trout life stages that are present during the winter period in the study areas are juvenile and adult. However, suitability-of-use criteria for juveniles were not modified during this study due to the difficulty of distinguishing between juvenile and adults and the low number of observations of juvenile trout.

STUDY AREA

The study areas selected were the South Platte River near Deckers, Colorado, and the Fryingpan River near Basalt, Colorado. Both study sections are downstream of reservoirs and contain high densities of rainbow and brown trout (Nehring and Anderson 1985). The high trout populations provide the opportunity to observe large numbers of trout in a relatively short time period. The water temperatures below the reservoirs keep the rivers relatively ice free, but they are still low enough to represent winter conditions. These were the two most important factors in choosing these study sites. Access was also considered, as snow could make transportation to some study streams impossible.

The South Platte River is a medium size river about 25 m wide, with discharges up to 42.5 m^3/s (1,500 cfs) in the study section. Winter discharges drop to about 0.5 m^3/s (15 cfs), with flows regulated by Cheesman Dam. The

major habitat features are long runs separated by riffle sections with occasional pools on the stream bends. Substrate is predominantly cobble and gravel with interspersed boulders. A section about 4.5 km in length was studied, with the upper boundary about 6 km downstream of Cheesman Dam (Figure 1).

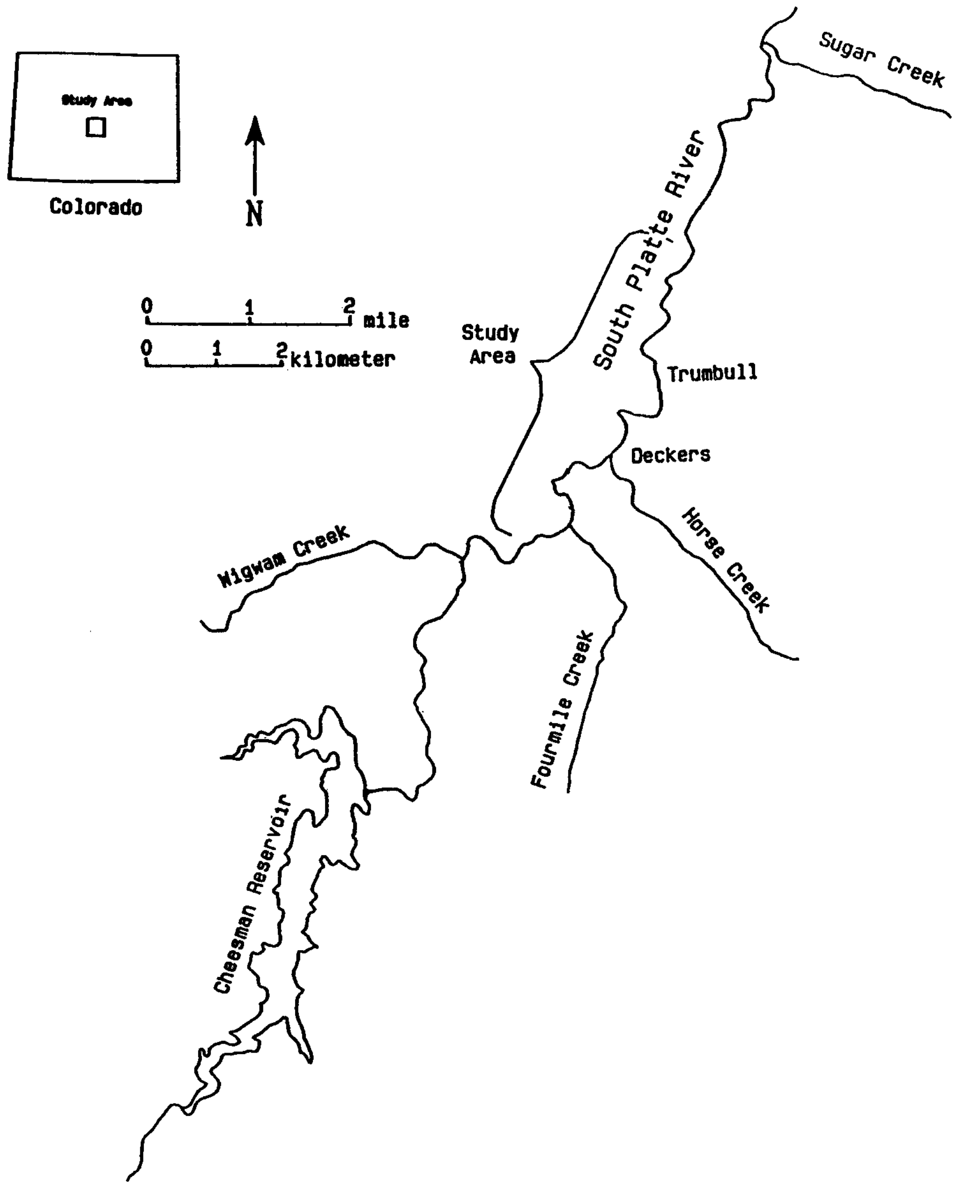

Figure 1. Trout observation locations on the South Platte River, Douglas County, Colorado.

The Fryingpan River is a smaller river, averaging about 17 m wide. This river is more characteristic of a higher gradient, larger substrate mountain river. Flows are regulated by the Ruedi Dam located about 19.3 km upstream of

the town of Basalt. The major habitat features are deep pools and long runs separated by riffle sections. Substrate is predominantly cobble and gravel, with numerous large boulders scattered throughout the stream. A 3.6 km section, downstream of Ruedi Dam, was studied during the sampling period (Figure 2).

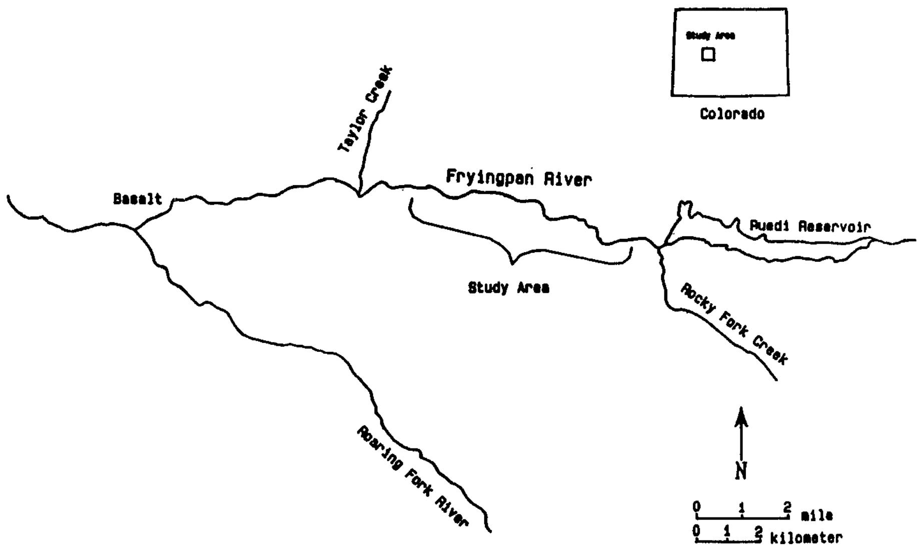

Figure 2. Trout observation locations on the Fryingpan River, Eagle County, Colorado.

METHODS

Sampling was conducted from January 6 through February 24, 1986, on both rivers. Habitat utilization data were collected by direct observation. Observations were made primarily by snorkeling, with limited bank observation, both of which provided accurate data collection without disturbing the fish. Bank observations, however, were limited to areas with relatively shallow depths, low turbidity, and little surface turbulence, i.e., shallow pool-type habitats near shore.

Data collected at each location included total depth, focal depth, mean column velocity, focal velocity, substrate, cover type, species, and life stage. The substrate code (Table 1) corresponded to the modified Wentworth scale. The cover code (Table 1) ranged from 1 for no cover to 4 for a combination of object and overhead cover (Raleigh et al. 1984a). Substrate codes ranged from 1 for plant detritus to 8 for bedrock. Adjacent substrate

Table 1. Substrate and cover codes used in winter habitat study.

Substrate code	Substrate type
1	Plant detritus/organic debris
2	Mud/soft clay
3	Silt (particle size <0.062 mm)
4	Sand (particle size 0.062 - 2.0 mm)
5	Gravel (particle size 2.0 - 64.0 mm)
6	Cobble (particle size 64.0 - 250.0 mm)
7	Boulder (particle size 250.0 - 4000.0 mm)
8	Bedrock (solid rock)

Cover code	Cover type
1	No cover
2	Object cover
3	Overhead cover
4	Combined object and overhead cover

sizes were partitioned into percent composition and coded accordingly. A code of 6.5 would represent an area of 50% cobble and 50% boulder. Lead weights and plastic floats were used as location markers to record stream position of each fish observed. The markers were color coded by species and life stage. Floats were attached by cords and positioned at the focal depth of the fish at each specific location.

Trout orient facing upstream in the current, so snorkeling was conducted in an upstream direction to avoid startling the fish from their positions. A cable attached to metal fence posts on the banks was placed across the river at the upper end of each sample segment. Tether ropes were attached to the cable and extended downstream through the sample segment. The snorkelers wore dry suits, full face hoods, dry suit mittens, mask, and snorkel. No fins were required, as the water depth rarely exceeded 2 m. After the ropes were positioned and left in place for 30 minutes, the observers attached ascenders to the downstream end of the rope and began moving upstream. The location of each undisturbed fish was marked using a coded weight and float. After sampling a section of river, usually a riffle-run or riffle-pool sequence, the observers returned to each location and recorded the data on field data sheets (Table 2).

Water depth and focal depth were measured to a tenth of a foot using a top-setting wading rod. Water velocity was measured with either a Price AA or Montedoro-Whitney electronic velocity meter. Substrate and cover were determined by visual observation after floats were positioned.

Table 2. Field form for recording observation data.

WINTER TROUT STUDY DATA FORMS

Stream Name: **Study Site:**

Date: **Time:**

Sampling Method:

Crew Members:

Discharge:

Temperature:

Observation:	1	2	3	4	5	6	7	8	9	10
Species:										
Life Stage:										
Frequency:										
Total Depth:										
Focal Depth:										
Mean Velocity:										
Focal Velocity:										
Substrate:										
Cover:										

Cover Notes:

Species Code:
Brook - Brk, Brown - Brn, Rainbow - Rbw; Adult - Ad, Juvenile - Ju

At the completion of the field study, the field data sheets were summarized and frequencies tallied for each variable. The variables used to generate the habitat utilization curves were total depth, mean column velocity, and substrate type. The analysis was limited to these variables for compatibility purposes, with the measurements taken for existing IFIM studies and habitat utilization curves.

RESULTS AND DISCUSSION

Several factors indicated that a winter habitat study should be carefully defined in terms of scope and purpose. Although there are many informative and innovative studies that could be conducted to coincide with the development of a winter IFIM utilization curve study, unpredictable conditions, limited light, and the effects of cold on working efficiency were found to be limiting factors. Depending on the number of observations, a 100-m section might take several hours, and only 200 m might be sampled in one day. If unnecessary measurements are taken, the length of the study might have to be extended significantly or the number of observations limited.

We experienced below 0 °C water temperatures and adverse weather conditions, and all equipment performed adequately. The dry suits and accessory gear were adequate even at water temperatures below 0 °C for extended periods of time (more than 30 minutes). Wet suit mittens were preferred over the gloves for hand protection. Hands became cold rapidly in the gloves and had to be heated with hot water occasionally, whereas the mittens kept hands warm throughout an entire snorkeling episode.

Due to time constraints, it may be more efficient to have at least one person recording after the snorkelers have started placing bobbers in position. The third person may also collect equipment and help to ensure the safety of the divers. Although it may be more time-efficient in wadable rivers to have a separate person recording data, in deep rivers it is probably more practical to use the underwater recording procedures discussed by Bovee (1986).

Although both study areas were located downstream of large hypolimnetic-release reservoirs, and earlier observations indicated the water was clear, there were some problems with visibility. During the early morning, there was little or no melting of snow and ice along the edges of the mainstem or in tributaries. During midmorning and afternoon, however, snow and ice began to melt, washing sediment and organic matter into the stream. Visibility was reduced dramatically in the South Platte River, especially downstream of one particular tributary. Thus, it may prove to be an important part of the site selection to identify tributaries that transport large sediment loads. In addition, snorkeling several times of the day prior to the study should be considered to determine if visibility is acceptable.

Downstream movements by divers (drift diving) have been used to estimate population sizes of brown and rainbow trout in streams (Richardson and Turner 1982; Hicks and Watson 1985). We found, however, that to approach salmonids without disturbing them, upstream movement was necessary. Although some of the

brown trout were not facing upstream, the rainbows were almost always facing into the current. In order to make adequate observations of undisturbed trout for microhabitat measurements, patience must be exercised, and early detection of factors that induce a startle response must be determined and avoided. There were three primary factors that startled trout during this study: bright color, rapid movement, and noise. Although these factors did not necessarily result in rapid dispersal of the fish, they did move from their undisturbed positions, and unbiased observations could not be made.

Our observations indicated that color was probably responsible for more startle behavior than sound or movement for brown and rainbow trout. During the study, two dry suits were used, one with blue and white colors on a black background and the other with red colors on a black background. Rainbow and brown trout did not appear to avoid the blue colored suit. However, at least the rainbow trout, which were more oriented to open water, appeared to avoid the bright red colors of the other suit. Instead of remaining in position in midstream, many trout were observed moving to the periphery of our field of vision. Bank observers also noted the fish moving away from the red suit. Similar results were found by Bovee (1986). To alleviate this problem, an article of clothing can be worn over the red portions of the suit. We used dark green colored rain gear and found it to be adequate in covering the visible areas. The yellow rock-climbing ascenders and white ascender ropes were also found to frighten trout. By dyeing the ropes brown and painting the ascenders black, this problem was resolved. While trout were observed avoiding the white ascending rope, they appeared to ignore the brown rope even when it was moving when the divers were ascending it. It is apparent when snorkeling that underwater objects appear to be dull in hue, and bright colors are absent. Trout are less startled, and more accurate observations can be made, if equipment is dull in color.

The second most important factor influencing avoidance of snorkelers by both rainbow and brown trout was abrupt movement. Kicking or sudden motions sent trout fleeing from their positions in the stream. By using the rock-climbing ascender technique, movement was limited to one arm slowly moving the ascender up the rope and then the snorkeler pulling himself upstream a foot or two at a time. Slow head movements also did not appear to startle the fish. Movement of the lifestage measuring bar also startled the fish, and the bar was not used after the first few attempts. Due to the inability to distinguish adults from juveniles, only those fish known to be within the lifestage size range were used. Cross-stream movement could usually be accomplished in faster currents by turning the body slightly into the current. In slow water, however, it was necessary to creep slowly on the bottom. Our observations were made in relatively shallow water (usually less than 1.5 m), so weight belts were not necessary. In deeper rivers, weight belts may be needed to achieve the desired depths.

The third most important factor influencing a startle response was noise created by swimming or walking in the river. This category could also be listed along with movement, as the two are closely related. Walking on the substrate probably makes the most noise, and fish were starled when movement was not slow and deliberate. Although fishermen were abundant in both streams studied, the sight and sound of a person crawling on the bottom of the stream was apparently alarming if not done slowly and cautiously.

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QUESTION AND ANSWER SESSION

David Winters

Q: How did you mark the vertical position of the fish for subsequent nose velocity and nose depth measurements?

A: We attached bobbers, which were our floating markers, to the sinkers with fishing line. The bobbers were adjusted to mark the position of the sighted fish at its approximate position above the streambed. If the fish was observed to be lying right on the bottom, we attached the bobber directly to the sinker itself.

Q: Was it your intention to measure a winter habitat where the fish bury themselves in the rocks?

A: We basically tried to measure every microhabitat in which we observed fish. We did make measurements for all the trout we found lying in the interstitial spaces of the rocks. We knew that brown trout favored these locations, particularly in the winter time, so we were looking for them. We were able to make observations and measurements on rainbow trout relatively quickly because they were more commonly found in open water. We weren't finding brown trout out in the middle of the streams. We then began to look more closely under boulders and between boulders and that's where we found them.

Q: How do you measure the velocity when they're lying right on the bottom between rocks, under rocks, and under overhangs? I ask this because it seems like in these circumstances, depth and velocity are not the important criteria here. But rather, the substrate providing the shelter that they seek is important.

A: Velocity measurements were made with a Montedoro-Whitney velocity meter, which utilizes a relatively small sensor probe. This meter was adequate in measuring all nose velocities, while a larger mechanical meter with the rotating cup mechanism would not have been sufficient to conduct measurements in some of the areas. The cover code incorporated the boulder-rubble substrate as a combination of object and overhead cover. By utilizing the cover code, factors other than depth, velocity, and substrate were addressed.

Q: What were the results of your comparison between the summer curves and those you developed for winter?

A: We're in the process of trying to get that data together and analyzed for publication. It should be available before too long, but it's still in the works at this time.

Comment from the floor: It seems to me that cover isn't really important, but rather, particle size and imbeddedness are important when the brown trout are lying down in the interstitial spaces.

A: I should clarify that although there have been studies, especially in the western part of the country, where juvenile salmonids actually burrowed into the substrate during winter periods, this was not observed in our study. Because we were only interested in adult fish, we did not examine the micro-habitat preference of juvenile trout. The adult trout were not actually burrowing into the substrate but were lying adjacent to or underneath boulders or between large cobble where velocities were minimal.

Q: How did you handle the turbulence component of cover?

A: We limited our cover descriptions to physical cover, but we did incorporate it to a certain degree. Where turbulence was clearly providing cover, we treated it as overhead cover and made a note. So, it is incorporated into overhead cover.

Q: Regarding your use of a bobber for a marker, is there anything you'd do differently to make that more efficient?

A: We were quite pleased with the way that the bobber-sinker arrangement worked and I don't see any way to make it work better than it did.

Q: How many observations did you have?

A: It was over 150 observations for each adult life stage of each species. We just weren't seeing enough juveniles and younger life stages to make it worthwhile, so we concentrated on the adults.

Q: What basic behavioral differences did you note between the rainbow and brown trout.

A: In the morning, the rainbow trout would be actively feeding in the middle of the river, while the brown trout would by lying in the interstitial spaces of the substrate and under the banks. Basically, the rainbow trout appeared to be much more active, even in very low temperatures, than the brown trout.

Q: What difference are you seeing between the winter and summer curves?

A: At this point, I can't tell because we've just begun to process the data to make that evaluation.

Q: What size were your adult fish?

A: Based upon size-class structure, we called any fish six inches or greater an adult. We had a measuring stick that showed the six-inch increment, but had difficulty getting close enough to determine whether a fish that was a little over or a little under was juvenile or adult. If it was in the 8-10 inch category, it was clearly an adult. If it was considerably less than six inches, it was clearly a juvenile. It was much more difficult to categorize fish that were near six inches.

Q: Was your interstitial space limited? It seems like you had mostly cobble there.

A: We had a lot of boulders in areas where there was considerable riprap. We found that the cobble areas alongside the stream near road construction were heavily used.

Q: Do you think the brown trout were feeding at night, or was that just a winter behavior?

A: I don't know. During the whole study, I never saw a single brown trout feeding. We did not conduct any nighttime operations, however.

CONSTRUCTING SUITABILITY CURVES FROM DATA

by

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INTRODUCTION

One purpose of the Instream Flow Incremental Methodology (IFIM) is to evaluate the relative amount of suitable habitat that would be available to a particular species (or life stage of a species) under different stream flows (discharges) or after channel restructuring. In order to do this, the habitat use or preference by the species (or stage) in question must be known. This knowledge is especially important, since it often represents the only biological information from which decisions with biological import follow.

The use of, or preference for, a habitat by a species usually is presented as the species response to differences in each habitat factor. If a species is responding to an environmental factor, a more or less smooth, monotonic, or unimodal response curve is expected. Species response is often expressed as the number of organisms occurring in a sample of a given range of a habitat variable, but also can be expressed as population density, productivity, or biomass associated with a particular habitat. Four microhabitat features of running water especially important in instream flow studies are depth, velocity, cover, and character of the substrate. The response of a species to any one of these can be represented by a curve where different values of the habitat factors are represented on the horizontal axis (also called the x-axis or abscissa) and values representing the species use or preference are indicated on the vertical axis (y-axis or ordinate) (Figure 1). Smoothing a cover or substrate curve, of course, only makes sense if these variables are represented on a ratio or interval scale.

Use and preference are usually scaled to a range of 0.0 (not used or preferred) to 1.0 (most used or preferred). A line or curve in the x-y plane represents the use or suitability of the habitat for the species. Such curves are also called "species criteria" or "suitability index curves." The x, y coordinates describing the curve are used in models that calculate the amount of suitable habitat present in a stream reach.

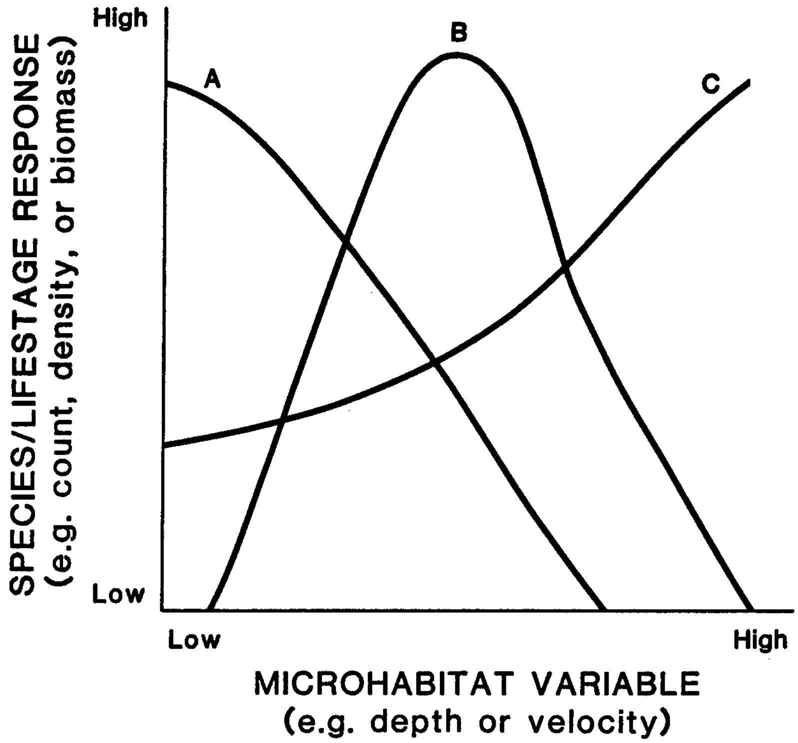

Figure 1. Three generalized species (or life stage) response curves with two species (a and c) showing a monotonic and one species (b) a unimodal response along an environmental variable. Species response can be measured by count, density, or biomass and expressed on an absolute or relative (e.g., percent) scale. Microhabitat, or any other environmental variable, must be expressed on a ratio or interval scale.

Suitability or preference curves are given to the IFIM as more or less smooth monotonic or unimodal response curves. The curves, however, are typically derived from data that do not appear smooth. The purpose of this paper is to investigate different curve-smoothing techniques for translating field data into an appropriate species response curve.

The following conventions are used in this paper. Suitability curves may represent the actual use of different ranges of a habitat variable by an organism (category II criteria) or the preference for particular habitats (category III criteria). Use and preference curves are very different (Armour, Fisher, and Terrell 1984; Bovee 1986), but since the purpose here is to investigate techniques for smoothing, the response variables (measured on the y-axis) can be, indifferently, use or preference. I use the phrase "species response" equivocally between these two senses. Indeed, the techniques described here can be applied to virtually any x-y plot; any special restrictions on the data, such as equally spaced x-values, are indicated where appropriate.

Suitability curves are often derived by first representing the data in frequency tallies, bar graphs, or histograms, but any of these may also be

plotted as a simple x-y scatter of the data, where the x-axis positions are the midpoints of the bar or histogram class intervals and the y-axis values are the heights of the bars (Figure 2). The y-axis positions are often represented as a percent of the sum of the y-values or as a percent or proportion of the maximum y-value.

Development of suitability curves (criteria) is most often an exercise in data description, not hypothesis testing. Seldom will a particular mathematical function be expected to fit an organism's distribution along an environmental gradient. Rather, species response data are taken as descriptive evidence for the functional relation of organism to environment. Curves, once derived, can stand as hypotheses to direct verification or experimental studies, for example, but this is a further step in analysis.

CURVE-SMOOTHING TECHNIQUES

FREQUENCY ANALYSIS

Frequency analysis (Bovee and Cochnauer 1977; Bovee 1986) is a simple, intuitive technique that is most often used with, but not limited to, count or frequency data, hence its name. Typical data include observations of microhabitat conditions such as depth, velocity, and substrate, as well as the presence, number, or biomass of organisms.

Frequency analysis is performed in turn for each of the habitat variables. The species response variable is plotted in a bar graph as a function of the microhabitat variable (Figure 2-a). When analysis is done by hand, it is convenient to sort the data by the values of the environmental variable and then to plot the sum or average of the species response values for each increment of the environmental variable. (For category III criteria the species response values should already have been adjusted to represent preference.)

Bar graphs, such as given in Figure 2-a for frequency of Dolly Varden over depth, are often choppy, not smooth. Still the overall shape of the response may be evident. Dolly Varden are not common at depths less than 0.2 or greater than 2.0 feet and are most common at depths of 0.5 to 1.0 feet. Frequency analysis is an attempt to make clear the overall shape of the response. First, the data are replotted with bars, or bins, having twice the width as in the original plot and heights equal to the sum (or average) of adjacent original bars. For example, the response values for the depths of 0.0 and 0.1 feet may be summed (or averaged) to give the height of a bar with its midpoint at 0.05 feet. Similarly, the responses for depths of 0.2 and 0.3 feet are combined giving a bar centered at depth 0.25 feet, and so on (Figure 3). The resulting aggregated (or stepped or clumped) bar graph appears smooth except perhaps in the right tail. (Imagine connecting the midpoints of the tops of the bars with a smooth curve.)

When intervals are taken by pairs, as in the example above, two different pairing arrangements are possible: any given bar can be paired either with

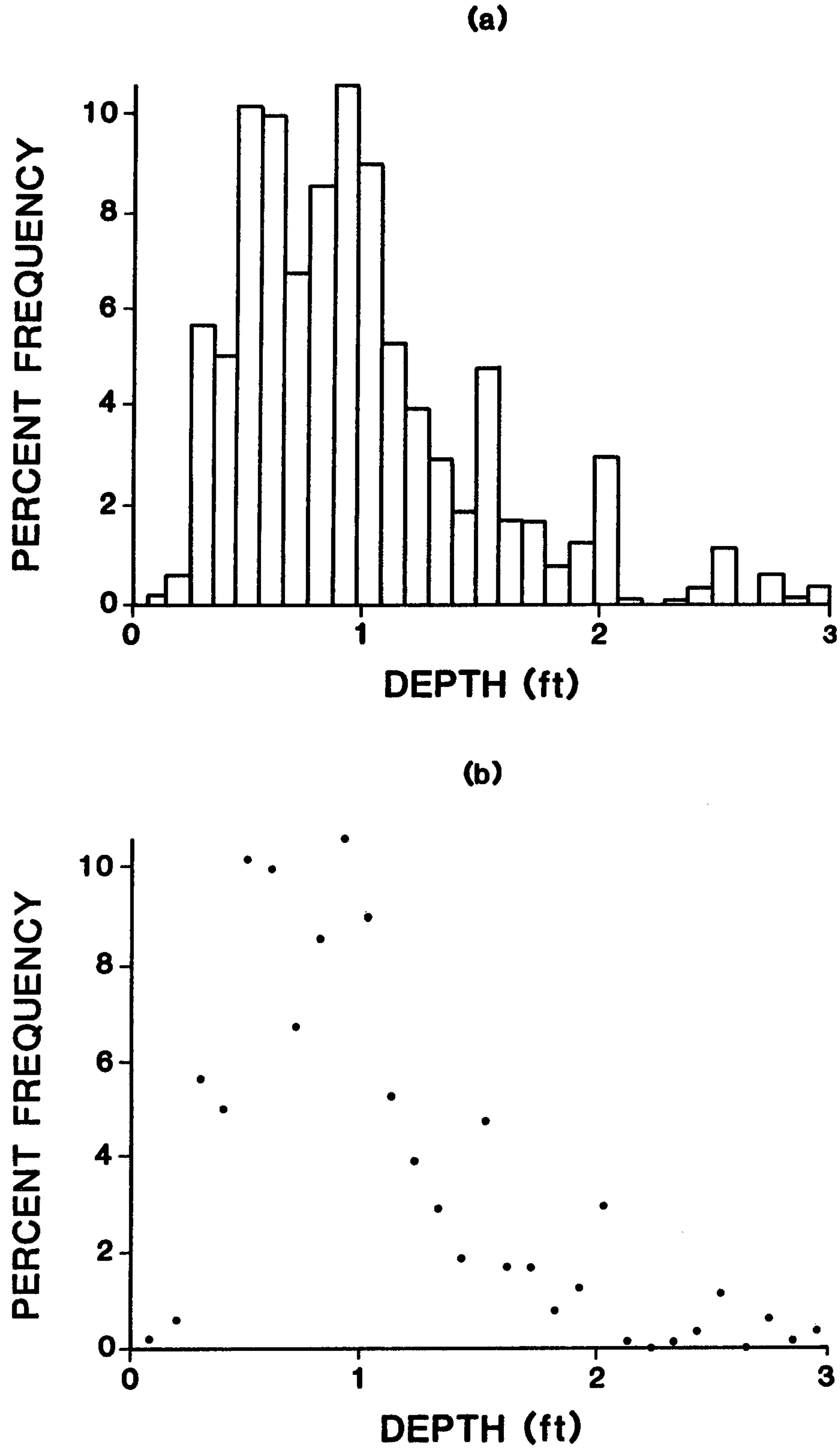

Figure 2. Response of Dolly Varden to depth. The same data are shown in bar graph (a) and scatter plot (b) form. Species response is expressed as a percent.

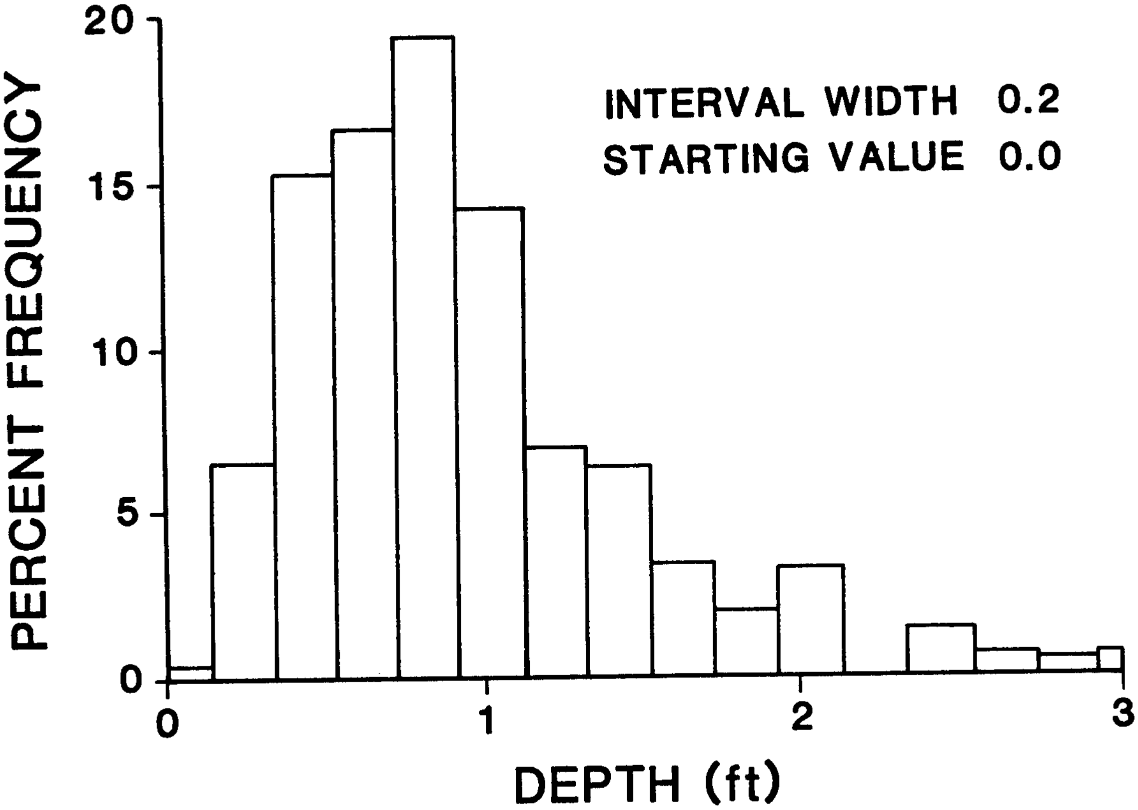

Figure 3. Response of Dolly Varden to depth represented with bars for each 0.2 feet interval. The first bar is the sum of the original values of species response for depth equal 0.0 and 0.1 feet expressed as percent frequency.

the bar to its left or to its right. Thus, it is possible to construct a second aggregated bar graph of the Dolly Varden data where responses at depths of 0.1 and 0.2 feet are summed and plotted above depth 0.15 feet, then responses for depths 0.3 and 0.4 combined, and so on (Figure 4). For these data the second or shifted bar graph is not as smooth as the first aggregation, having a dip near 0.6 feet. In frequency analysis, the investigator may settle on one of the bar graphs aggregated over 0.2 foot intervals (Figure 3 would be the obvious choice in this case). But if neither of these plots is satisfactory, analysis can proceed by aggregating the data in 0.3, 0.4, or 0.5 feet wide bins. Note that there are three possible ways to combine the data in 0.3 foot bins, four ways for 0.4 foot bins, and so on, depending on which initial depth value is chosen for the starting point.

The Dolly Varden versus depth data aggregated on 0.4 foot intervals are given in Figure 5. Each of the four bar graphs generally shows a smooth response to depth. Notice, however, that the position of the peak may be anywhere between 0.45 and 1.15 feet and that the occurrence at depths below about 0.25 feet varies ten-fold among the four plots. Thus, smoothness of response has been paid for in accuracy (Sokal and Rohlf 1981; Bovee 1986).

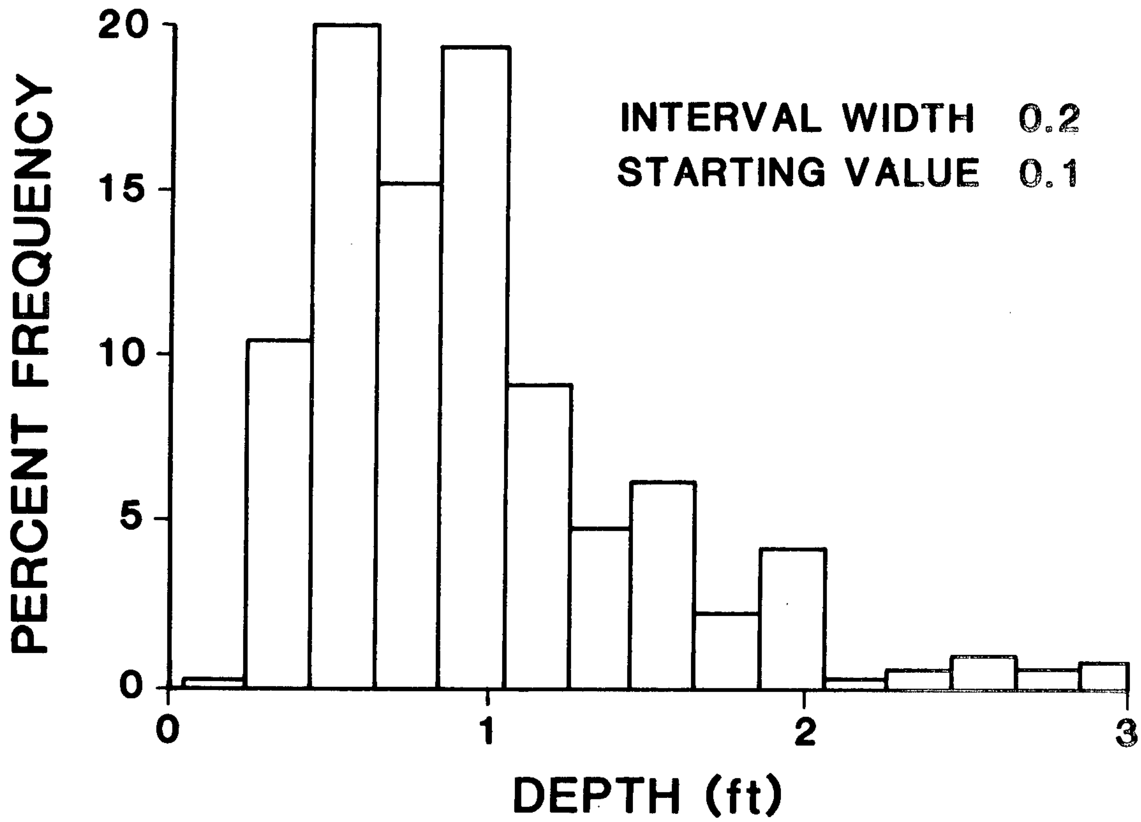

Figure 4. Response of Dolly Varden to depth represented with bars for each 0.2 feet interval. The first bar is the sum of the original values of species response for depth equal 0.1 and 0.2 feet expressed as percent frequency.

Other features of frequency analysis can be seen in the plots of Dolly Varden occurrence along a velocity gradient (Figure 6). The figure shows the raw data and the results of frequency analysis with 0.3 feet per second bins. Again, the grouped plots are smoother than the raw plot, but the grouped plots differ, this time with respect to the overall shape of the species response. Two of the three grouped plots show that more fish occur in the lowest velocity interval, but the third plot shows the response increasing from the lowest to the second lowest velocity interval. That is, ignoring the small fluctuations in the tails of the graphs, two of the plots indicate that the response to velocity falls off monotonically, while the other indicates a unimodal response.

Here the discrepancy can be explained by considering the way frequency analysis treats (or fails to treat) the first and last intervals of the velocity bar graph. If intervals are grouped starting with the smallest velocity value, then the first (aggregated) bar has a width of three original intervals. Intervals grouped starting with the second or third original value give full width (aggregated) bars from the starting point and beyond, but leave a narrower bar to represent the lowest velocities. (In a similar manner, the bars representing the highest velocity values may also be narrow.) One

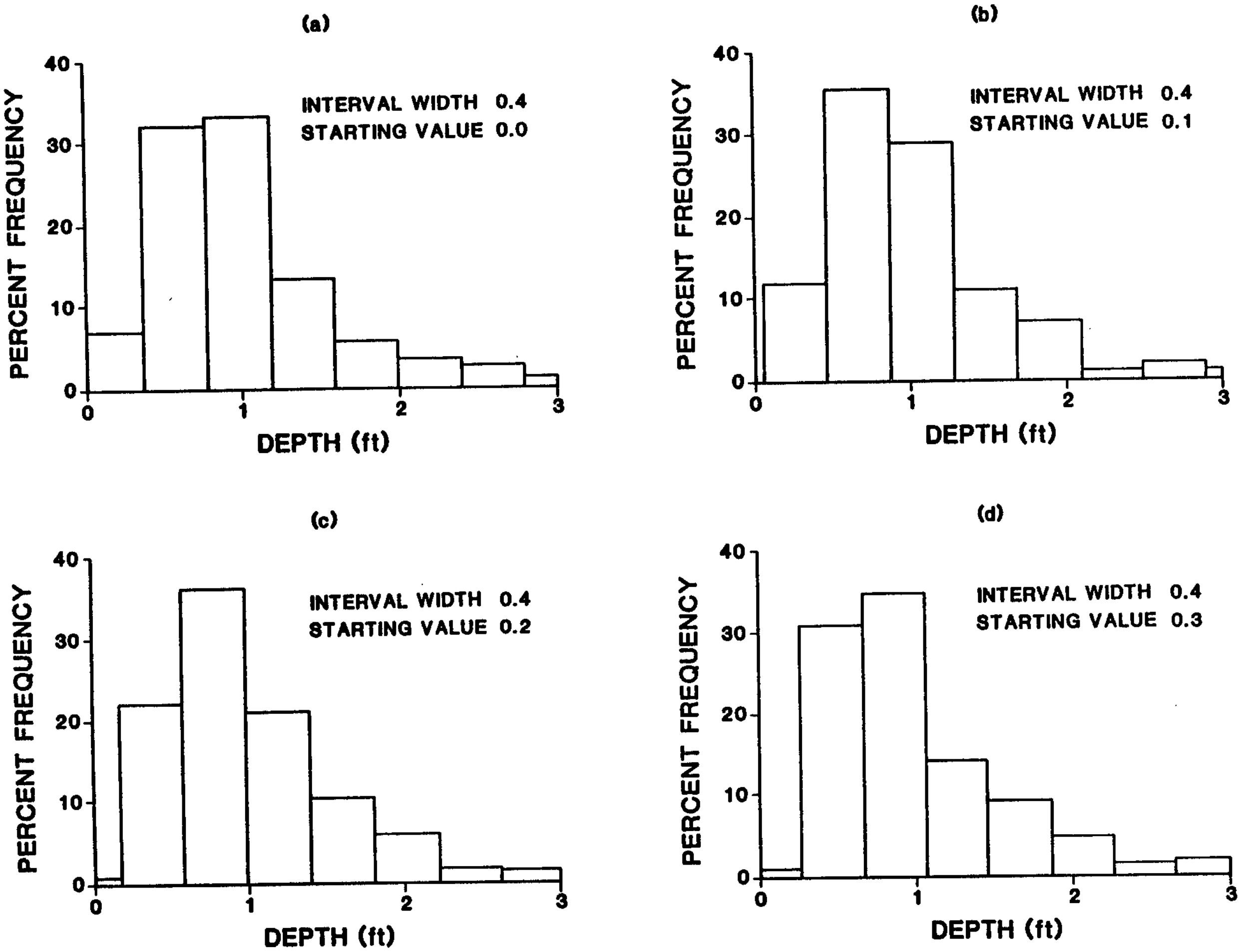

Figure 5. Response of Dolly Varden to depth represented in the four possible ways to obtain intervals 0.4 feet wide.

way to overcome this difficulty would be to include (average) the narrow bar in with the first full-sized bar. This would give extra wide bars on the edges of most of the aggregated bar graphs and dilute the contribution of the data values at the edges of the distribution.

Another possibility is to adjust the height of the narrow bars as a function of the number of original x-axis values contributing to it. For example, in the plot where the first grouped bar begins at 0.1 feet per second (Figure 6-c) only one original value contributes to the first (narrow) bar's height, while three values contribute to the other bars. Multiplying the first bar's height by three would make the narrow bar commensurate with the rest. But this would give three times more weight to edge data values and perhaps exaggerate their importance.

Frequency analysis as so far described uses equal bin widths wherever possible. But summarizing data into unequal bin sizes may also be appropriate (Velleman and Hoaglin 1981). Since the tails of a species' distribution are often undersampled, compared to the middle, wide bins at the tails may well smooth over sampling error, while narrow bins remain adequate for portraying data near the mode. Combining bins in a piecemeal way merely to gain local

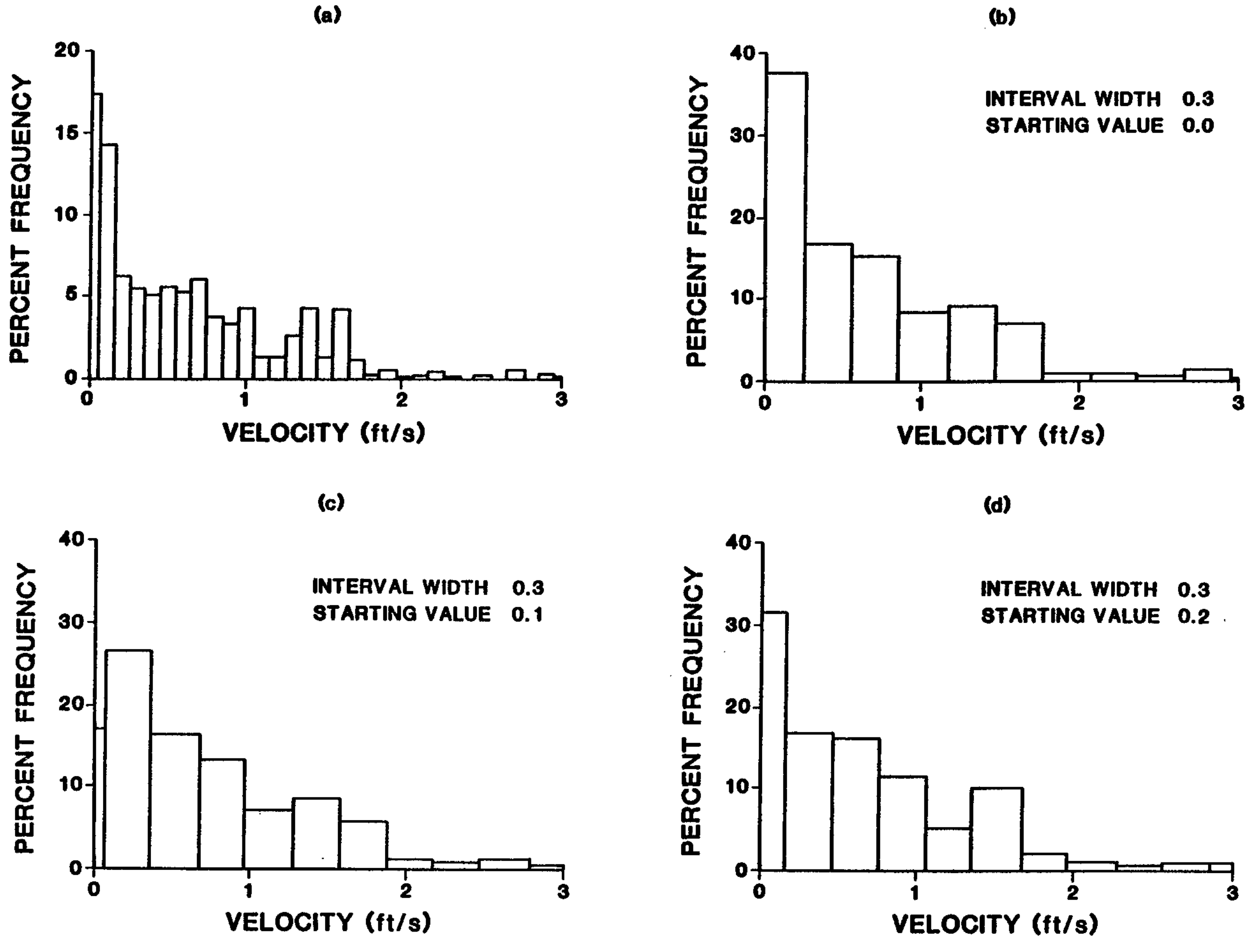

Figure 6. Response of Dolly Varden to velocity. Response is shown for velocity intervals of 0.1 feet per second, the interval of original measurement (a), and for the three possible ways to obtain intervals of 0.3 feet per second (b, c, d).

smoothness, however, borders on the arbitrary and may reveal more of the investigator's wishes than the message in the data. For example, selective combining of bins for the Dolly Varden versus depth data (Figure 2) might be appropriate for smoothing the tail beyond 2.0 feet and the small dip from 0.3 to 0.4 feet. Combining bars in the region of the highest response, however, could result in a peak response near 0.5 feet or near 1.0 feet, depending on which bars are combined.

Many computer program packages (BMDP, SAS, SPSS) use rules to automatically select the bin width to use in constructing a histogram, bar graph, or stem and leaf display. For example, the BMDP procedure (P5D) that plots histograms estimates the number of intervals by $8 \times (\log_{10}N) + 2$, where N is the sample size or number of frequency observations (Dixon and Brown 1979). A similar rule suggested by Dixon and Kronmal (1965) and found to be generally effective by Hoaglin, Mosteller, and Tukey (1983) estimates the number of bins as the integer part of $10 \times \log_{10}N$. They also suggest the number of bins be estimated by the integer part of $2 \times N^{\frac{1}{2}}$ if N is less than 50. For the Dolly

Varden depth and velocity data, with N a little greater than 1,000, these rules indicate a bin width of 0.1.

Choosing a desirable bin width or, what amounts to the same, the number of bins to use depends on the goal of the analysis. The rules mentioned above were designed to display data for visual inspection. The data are presented to reveal patterns that might be present, including multiple modes. These rules, therefore, may not be appropriate to the goal of producing a unimodal or monotonic species response curve. Other rules used by statisticians to select interval width also may not be appropriate for suitability curve construction, since they attempt to fit a histogram to an assumed density function, usually Gaussian. These rules and others are discussed by Hoaglin, Mosteller, and Tukey (1983).

Once an appropriate, smooth bar graph has been selected, a suitability index curve is constructed by connecting the midpoints of successive bars with straight lines. A slight modification is to connect midpoints, excepting those of bars that define the peak of the curve. The peak part of the index curve is defined by the top of the highest bar. Each corner of the highest bar is then connected to the midpoint of the next lower bar.

If either tail of the curve approaches the x-axis, the midpoint of any end bar is connected to the axis. One way is to draw a straight line from the middle of the edge bar to the midpoint of the next empty bin of the same width. This may result in projecting too wide a tail, however if for example the edge bin includes some original (raw) values of zero. A more appropriate procedure is to connect the suitability curve to the x-axis at a point indicated by the original, ungrouped data plot. If either tail of the curve does not drop to near the x-axis, then a decision about how to project the curve beyond the data must be made.

Once the bars are connected with straight-line segments, suitability index values are calculated by dividing the y-axis value of each segment's end points by the maximum y-value in the plot. Each of these values is paired with the appropriate x-axis value to give a set of ordered x, y pairs that define the suitability index curve.

Many of the advantages and disadvantages of frequency analysis have already been mentioned. The method is easy to understand and simple to compute. Hand plotting and calculation of simple sums or averages is all that is needed, and if plots are made for each aggregation interval, then the investigator always has simple visual representations of the progress of the analysis. The method is also fluid in that it lets the investigator interact with the data by responding to bimodal distributions or curious behavior in the tails. Several computer packages are available that can produce bar graphs with various interval widths and starting points.

One disadvantage of frequency analysis stems from one of its advantages, for if the investigator can make decisions about how to proceed at different stages of the analysis, then different investigators can come to different conclusions. That is, the method is in part ad hoc. It does not explicitly prescribe decisions the investigator must make concerning which bin width to use, which starting point to use, and how to deal with the tails of the

distribution. A second disadvantage has already been mentioned in that smoothness is attained at the expense of accuracy. A third disadvantage is that there is no standard way to compute residuals.

REGRESSION ANALYSIS

Least squares regression is an obvious statistical technique to apply to the problem of deriving smooth species response criteria from data. Since most scatter plots of species response over microhabitat factors suggest a curved rather than a straight line function, polynomial regression is the usual choice. Two different approaches that use polynomial regression to derive suitability curves have been used by instream flow researchers (Gore and Judy 1981; Orth and Maughan 1982; Morin, Harper, and Peters 1986). The technique is generally described in Sokal and Rohlf (1981), Weisberg (1980), and many other statistics texts. Both techniques express species response as a polynomial function of a single microhabitat variable. (Multiple regression relating species response to a polynomial function of more than one environmental variable is not covered in this paper.)

The first technique directly relates species response to environment by fitting species response to a quadratic, cubic, or higher degree polynomial of a single environmental variable. A cubic fit of species response to depth for example is given by the following model

$$SR = b_0 + b_1 d + b_2 d^2 + b_3 d^3 + e \quad (1)$$

where SR is species response, the b's are the regression coefficients to be estimated, d is depth, and e is residual error. Since a species response to environment is expected to be either monotonic or unimodal rather than multimodal, higher degree polynomials might not be appropriate.

The quadratic fit of the frequency of Dolly Varden to depth (Figure 7) is significant ($p < 0.001$), but not strong (adjusted multiple r-squared = 0.35). The rather poor fit can be seen in the patterning of the residuals about the regression curve; first they group below the fit then above then below again. Notice also the high intercept, which without adjustment by the investigator, would give a high suitability for a depth of 0.

The intercept problem can be solved in this case by forcing the regression through the origin. This is done by leaving the constant or intercept term (b_0) out of the model. Such a regression for the Dolly Varden versus depth data (Figure 8) seems to fit the data better than the regression including the constant (adjusted multiple r-squared = 0.55, $p < 0.000$), but since an intercept was not estimated the r-squared is inflated. Even though the curve goes through the origin, this fit is poor. The residuals are still patterned, but the curve is mostly symmetrical, while the data apparently are not. The peak is shifted to the right, and the right hand tail is too fat.

A cubic regression on the same data (Figure 9) improves on both quadratic fits ($p < 0.000$ and adjusted multiple r-squared = 0.71), but residuals continue

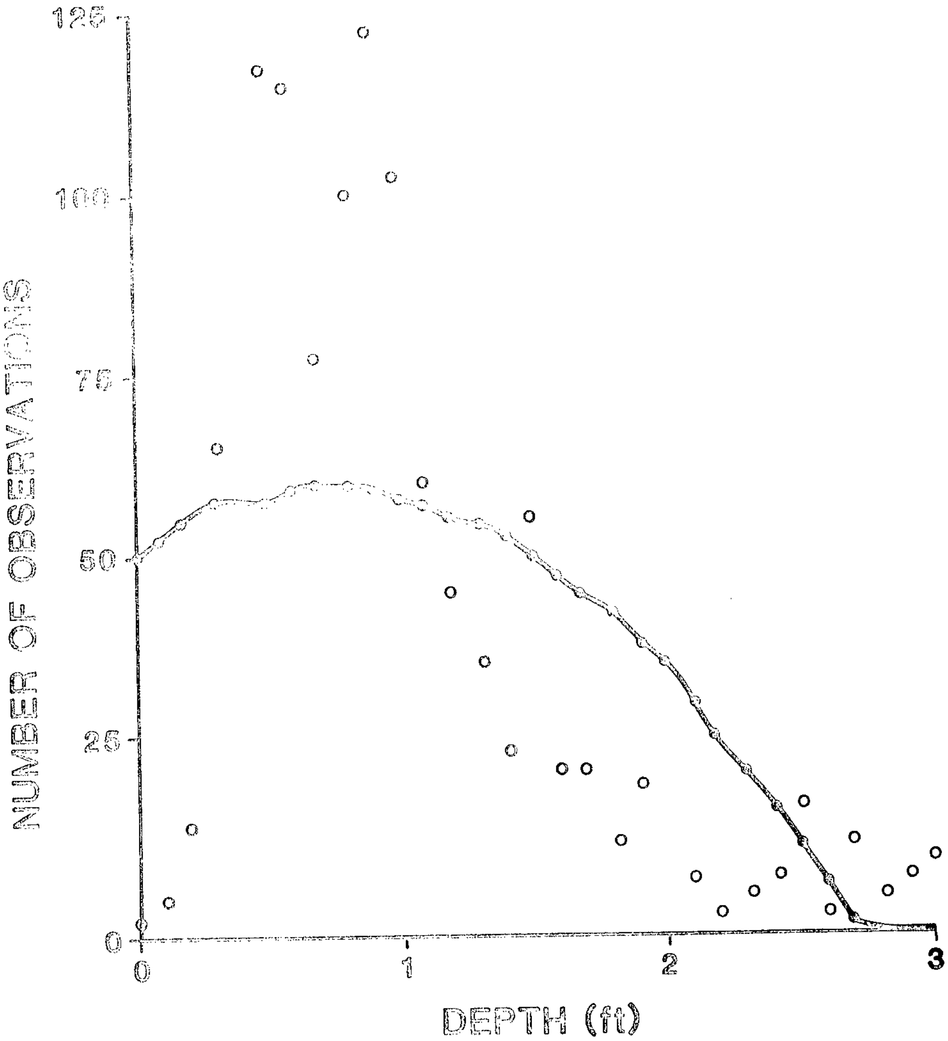

Figure 7. Response of Dolly Varden to depth (open circles), fit with a quadratic function (connected closed circles) by polynomial regression. $N = 49.6 + 23.0d - 15.8d^2$.

to show pattern. Notice that the intercept is near zero, where it should be, but now the other end of the curve is suspicious. The rise in the right hand tail suggests a bimodal response to depth that is probably not real.

A fifth degree polynomial fit is shown in Figure 10. Again the fit is improved ($p < 0.000$ and adjusted multiple r-squared = 0.79). If the small hump on the right hand side were not there or could be ignored, then a suitability index that followed the data fairly closely would have been found.

A second way to apply regression analysis to construct species suitability curves was used by Gore and Judy (1981) and later by Orth and Maughan (1982). Here the cumulative frequency distribution of species response to a habitat variable is fit with a fourth degree polynomial of the habitat variable. Cumulative frequency of Dolly Varden versus depth is given in Figure 11. The

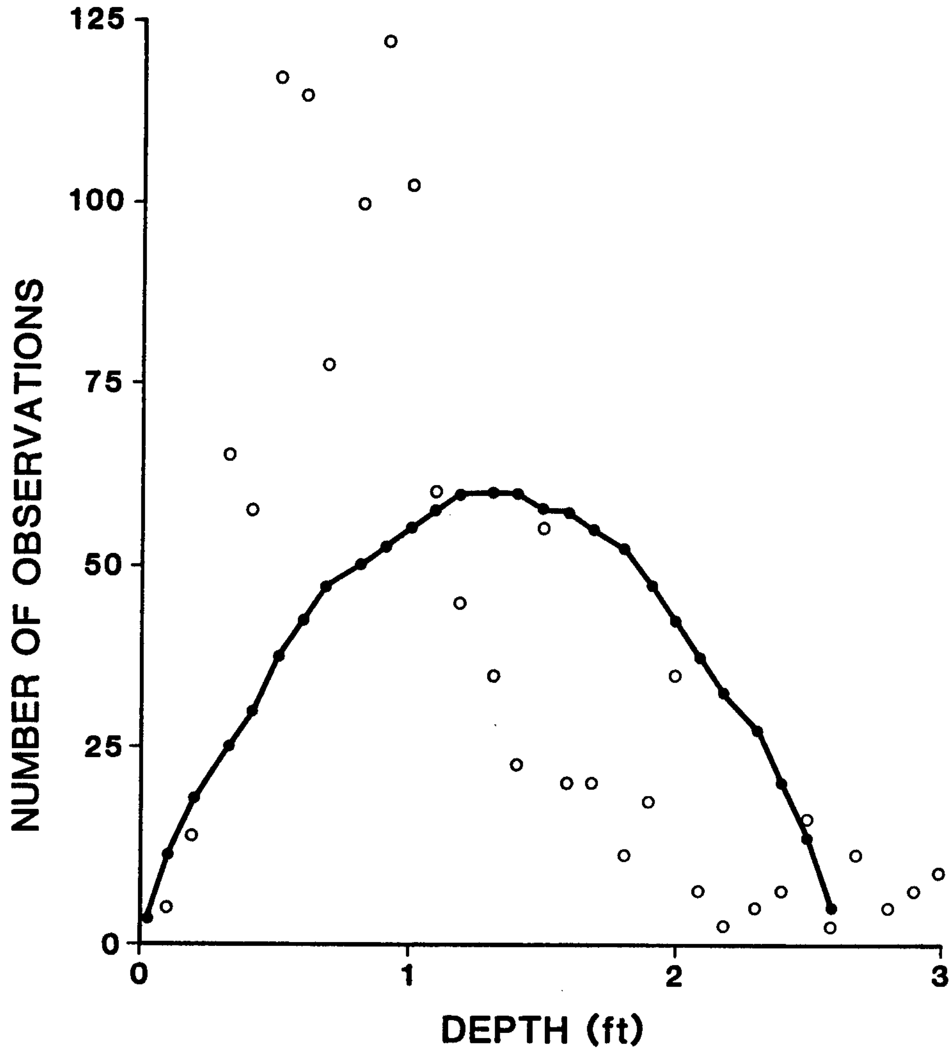

Figure 8. Response of Dolly Varden to depth (open circles), fit with a quadratic function (connected closed circles) by polynomial regression. This function was forced through the origin by not estimating an intercept term. $N = 88.2d - 33.6d^2$.

fourth degree polynomial fits this plot very closely ($p < 0.000$ and adjusted multiple r-squared >0.99), so close that it is not presented.

A curve representing species response to depth is retrieved by taking the first derivative with respect to depth of the fourth order polynomial. This results in a third order polynomial relating response to depth, which is also not given, since it closely resembles the cubic regression curve presented above (Figure 9). This resemblance, however, suggests a question. How can two such similar response curves, constructed from the same data, have such different regression statistics, especially the value of r-squared? I consider the r-squared that exceeds 0.99 to be suspect.

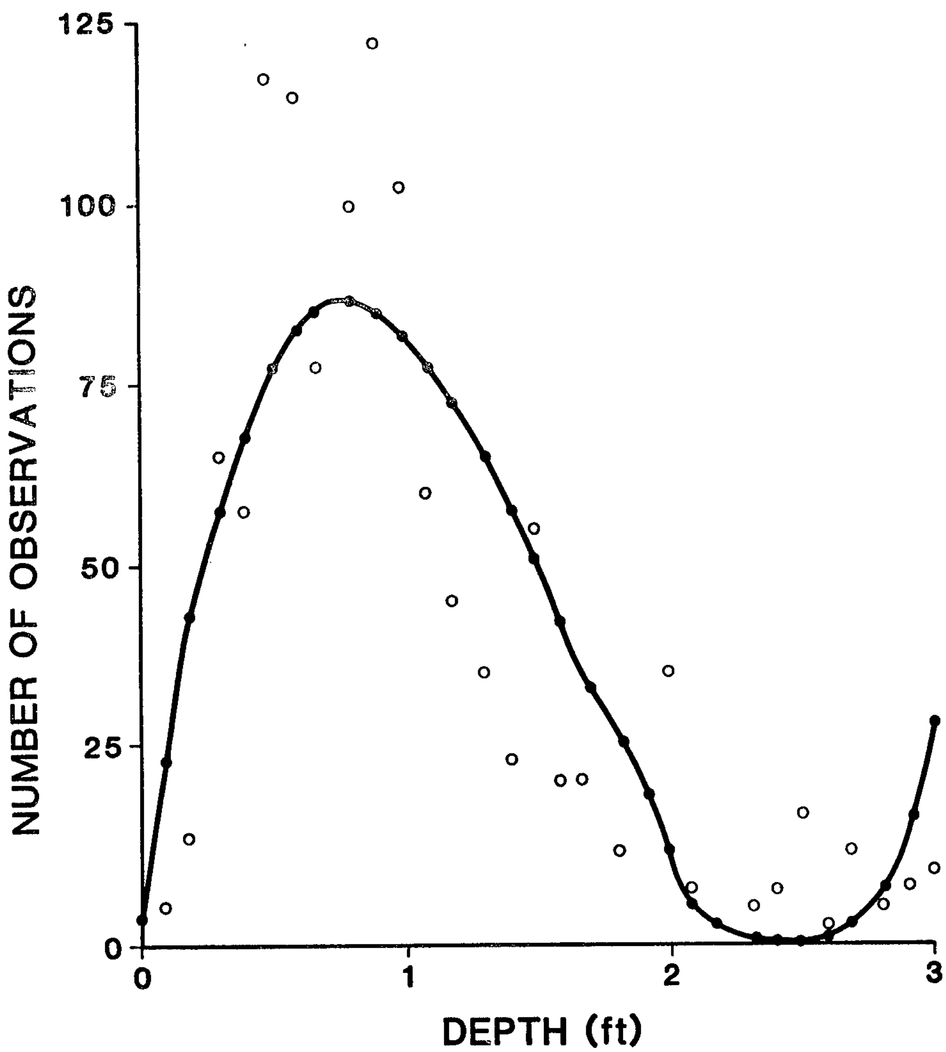

Figure 9. Response of Dolly Varden to depth (open circles), fit with a cubic function (connected closed circles) by polynomial regression. $N = -0.8 + 243.0d - 202.0d^2 + 41.8d^3$.

Consider performing the cumulative regression technique on random data. Figure 12 shows uniform random data generated to have the same ranges as the Dolly Varden versus depth data. If this represented a real species, then no trend in response to depth would be evident. Now look at the cumulative frequency distribution (Figure 13), which, as it should, runs more or less diagonally across the plot. But what is important is that it also forms a fairly smooth curve. The fourth order polynomial regression for this cumulative plot is highly significant, having a larger F value and a slightly larger adjusted multiple r-squared (>0.99) than the Dolly Varden data.

Evaluation of regression analysis as a method for constructing suitability criteria can begin by considering the explanation for these inflated regression statistics. Regression on cumulative, rather than simple or straight, frequency violates one of the assumptions of regression analysis, that the

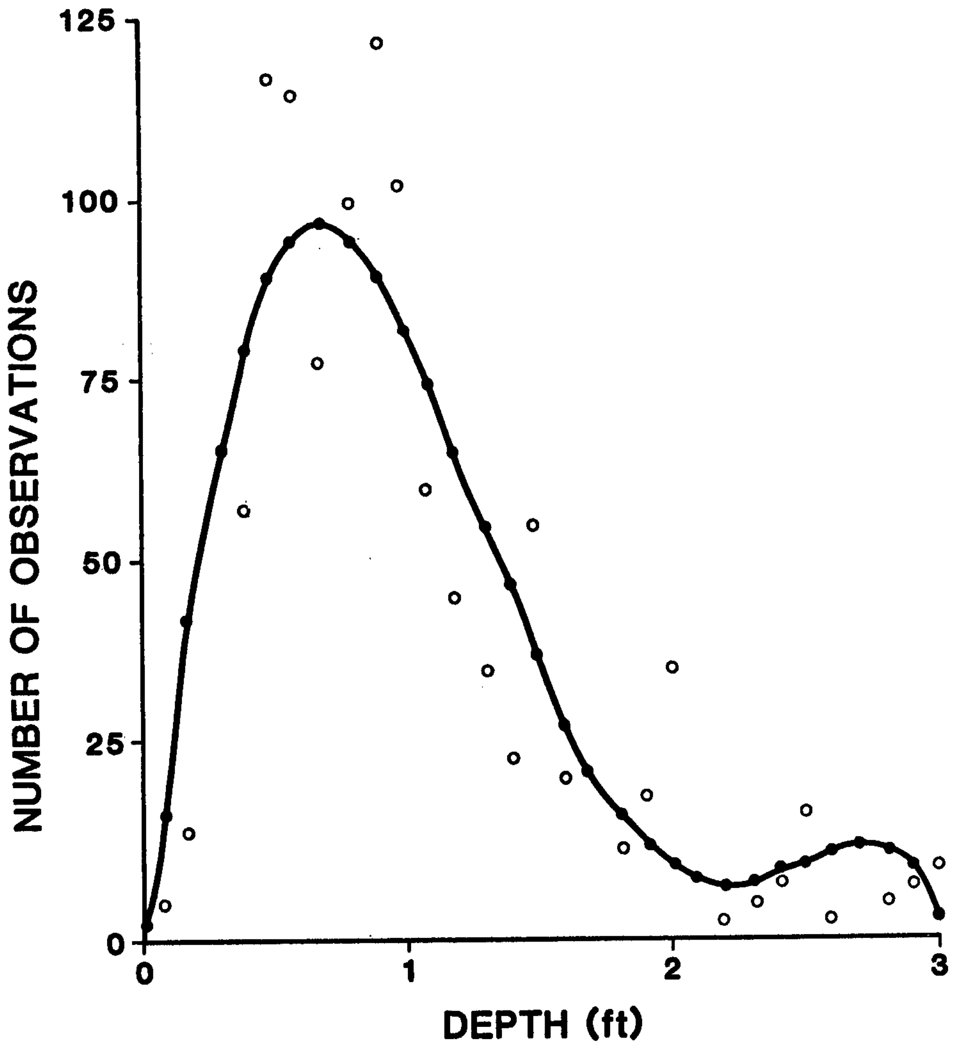

Figure 10. Response of Dolly Varden to depth (open circles), fit with a fifth degree function (connected closed circles) by polynomial regression. $N = -22.7 + 397.4d - 404.0d^2 - 107.5d^3 + 8.8d^4 - 4.7d^5$.

y-values for each x-axis position be independent (Sokal and Rohlf 1981). And here they are designed not to be, since each successive y-value includes the sum of all those below it.

There seems to be no reason to prefer the cumulative regression technique over the more standard and straight forward technique described above, which uses frequency (not cumulative frequency). This is especially so since, if other assumptions of regression are met, both methods will give final species curves of nearly the same shape. And regressing simple frequency on a habitat variable will not give such misleading values for the significance (p of F) or strength (r-squared) of the relationship.

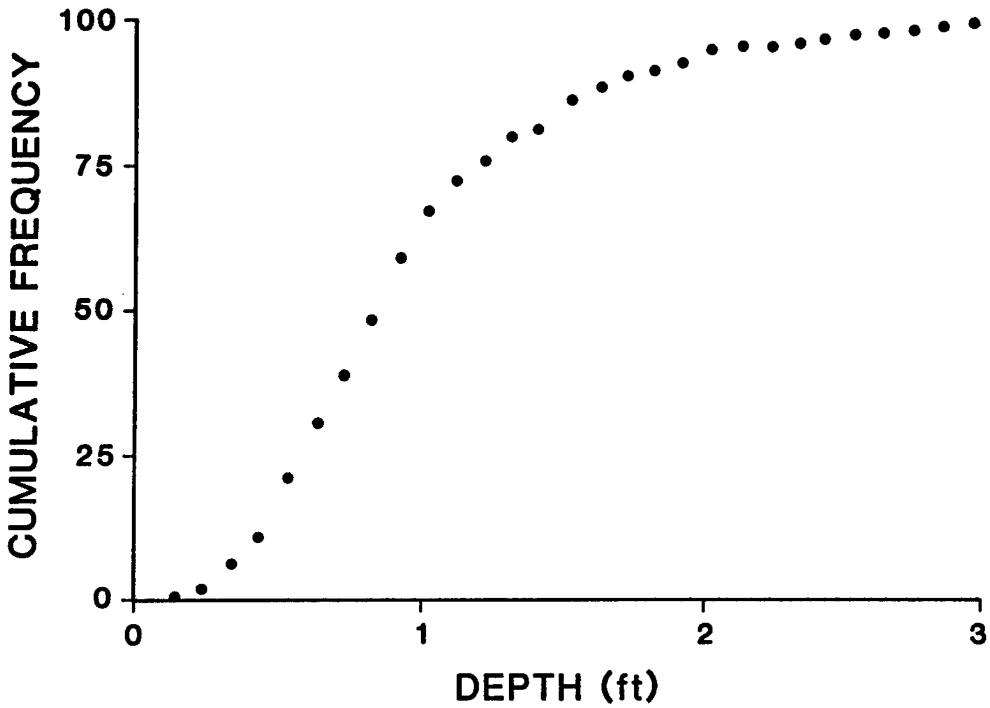

Figure 11. Response of Dolly Varden to depth expressed as cumulative percent frequency.

Inflated indications of significance and strength are shortcomings of the cumulative regression technique, but other problems pertain to both methods. The Dolly Varden data explored above provide examples of spurious intercepts, tails, and modes. It is also possible for the regression curve to dip below the x-axis, indicating negative frequency or biomass, results that are definitely spurious. These features of the regression curve could be changed by the investigator before calculating the final suitability curve (e.g., chop off a rising tail or smooth over a secondary mode).

Other assumptions of regression are probably violated even for the frequency versus habitat data, which may help explain some of the shortcomings just mentioned. First, regression assumes that the x- and y-axes are unbounded. But depth and velocity are both bounded at 0. Percent frequency, biomass, or any of the usual measures plotted on the y-axis also are truncated at 0. Regression allows, even demands, the possibility of negative species response values, but such values are biologically meaningless, and any method that produces them is suspect.

Second, regression assumes that the variance or scatter of the data is roughly the same for all values of the independent variable. This is unlikely for the sort of data analyzed for suitability curves, since high abundances typically have high variances, and low abundances are associated with low variances. This problem often can be overcome with suitable transformation of the raw data. Of course the regression estimates have to be transformed back to their original units before deriving the final suitability curve.

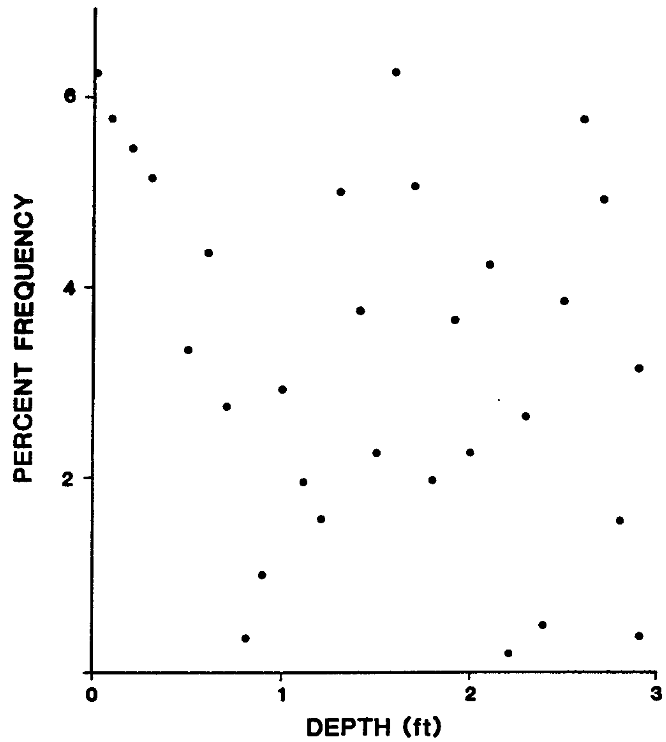

Figure 12. Uniform random data generated to have the same ranges as the Dolly Varden versus depth data.

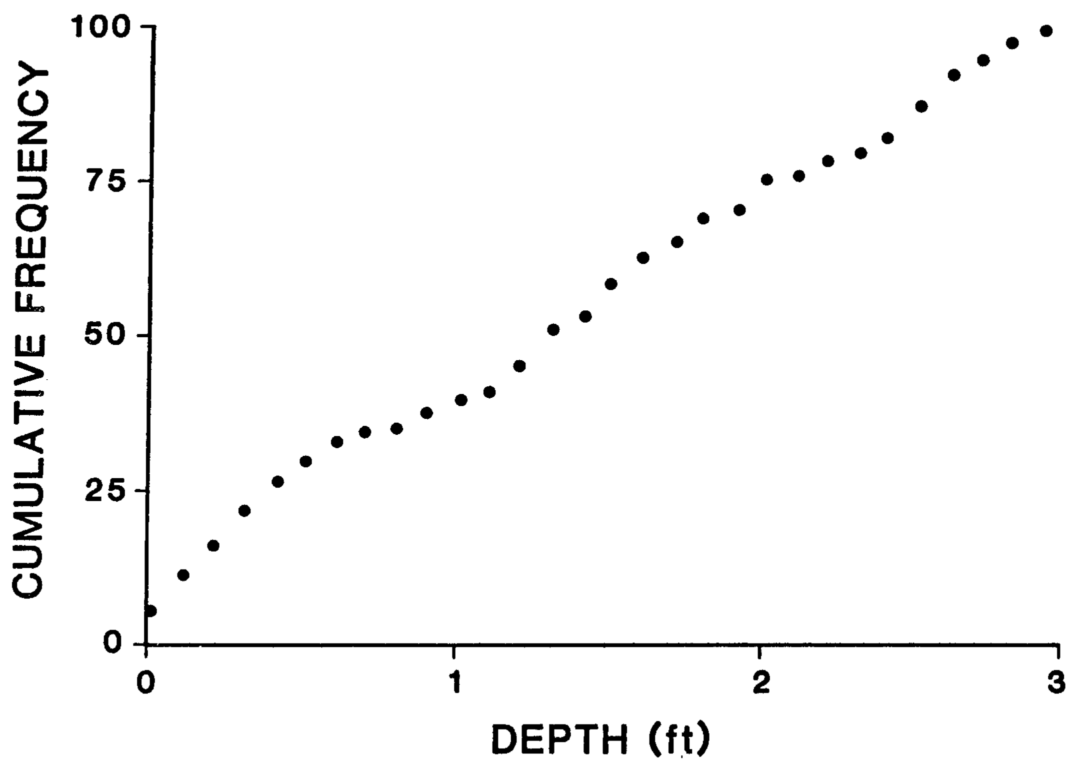

Figure 13. Cumulative frequency distribution of uniform random data given in Figure 12.

Third, unequal variances and the susceptibility of least squares regression to extreme data (outliers) can explain the poor visual fit of many of the regressions (e.g., Figure 7). In frequency analysis, outliers are averaged in with surrounding points, which tends to reduce their influence; but in regression, outliers pull the regression line away from surrounding points. This is because the squared distance of a point to the regression line is minimized in constructing the regression curve. Further, the higher the order of polynomial fit the more likely the resulting curve will match the random variation in the observed data rather than the overall shape of the curve (Weisberg 1980).

The advantage of regression analysis for constructing suitability curves is that it uses a familiar set of techniques that are widely available in computer packages. Regression provides for computation and analysis of residuals and gives statistical estimates of how good the smooth fits the raw data. These advantages are somewhat lessened, however, when you consider that, as in frequency analysis, many decisions are left to the investigator, including what degree polynomial to fit, how to deal with end values or other anomalies, and whether or not to transform the raw data.

NONPARAMETRIC TOLERANCE INTERVALS

The method of nonparametric tolerance intervals avoids many of the problems of regression because it is free from assumptions about the distribution of the variables and their variances and is not affected by the presence of outliers. It was first used in instream flow research by Gosse (1982) and has been described by Bovee (1986) for the construction of use and preference criteria. The method is based on the statistical work of Wilks (1941), Murphy (1948), and Somerville (1958). The method is summarized in Remington and Schork (1970) and Conover (1980).

A note on terminology is in order. The species response curve referred to in this paper can be thought of as representing the ecological tolerance of a species to the microhabitat variable under consideration; this is similar to the physiological tolerance of species to environment, but under field, not laboratory conditions. Now the use of the word "tolerance" in the name of this method has a different, statistical, meaning akin to the meaning of "confidence interval" (Conover 1980). Confidence intervals give a range within which an unknown population parameter lies, whereas tolerance intervals give a range within which a certain proportion of a population lies. Both intervals of course are always asserted with a specific confidence coefficient.

The basic idea of this method is, for example, to assign a suitability index of at least 0.1 to the central 95 percent of the population, of at least 0.2 to the central 90 percent, of at least 0.5 to the central 75 percent, and of 1.0 to the central 50 percent.

The suitability index value to assign to each percentage of coverage is calculated as follows

$$SI = (1 - P) / N \tag{2}$$

where SI is the suitability index, P is the proportion of the population (i.e., 50 percent = 0.5 = P), and N is a normalizing factor equal to the largest value the quantity (1 - P) takes among the set of percentages chosen, that is, the P for the interval to be assigned a suitability of 1.0.

The number of observed winter steelhead redds (Hunter 1973, cited in Bovee and Cochnauer 1977) for different stream velocities is given in Figure 14, and a suitability curve using nonparametric tolerance intervals is given in Figure 15. The curve was constructed as follows. A confidence coefficient of 90 percent was chosen, and critical tolerance interval values for 95, 90, 75, and 50 percent of the population were interpolated from the table in Somerville (1958) for a sample size of 257. These values are 8, 28, 77, and 163 and represent the number of observations to exclude from the tails (half from each tail) in order to leave the appropriate central percentage (95, 90, 75, and 50 percent) of the population.

The published tables do not give values for sample sizes less than 50, but they are available in graph form (Murphy 1948). Representative values have been read from the graphs and are presented here (Table 1).

Table 1. Nonparametric tolerance limits for sample sizes (n) less than 50. Values are given (for two confidence levels, 0.95 and 0.90) for tolerance intervals spanning 50, 75, 90, and 95 percent of the population. These values represent the number of observations to exclude from the tails in order to leave the indicated percent of the population. The values in the table were read from graphs in Murphy (1948).

	Confidence Level							
	0.90				0.95			
n	50%	75%	90%	95%	50%	75%	90%	95%
15	6	2	-	-	5	2	-	-
20	8	3	1	-	7	2	-	-
25	10	4	1	-	9	3	-	-
30	12	5	1	-	11	4	1	-
35	14	6	2	-	14	5	1	-
40	16	7	2	1	15	6	2	-
45	18	8	3	1	17	7	2	-

The percentage of the data spanned at each step could of course be changed in order to span a narrower central percentage of the population (e.g., 90, 80, 60, 40, and 20 percent), but the percentages first given are convenient because tables for them have been published (Somerville 1958, reprinted in Remington and Schork 1970; Bovee 1986). Figure 16 gives the suitability curve derived for the steelhead data presented above, but with the narrower percentages of the population covered at each step. Figure 17 shows both

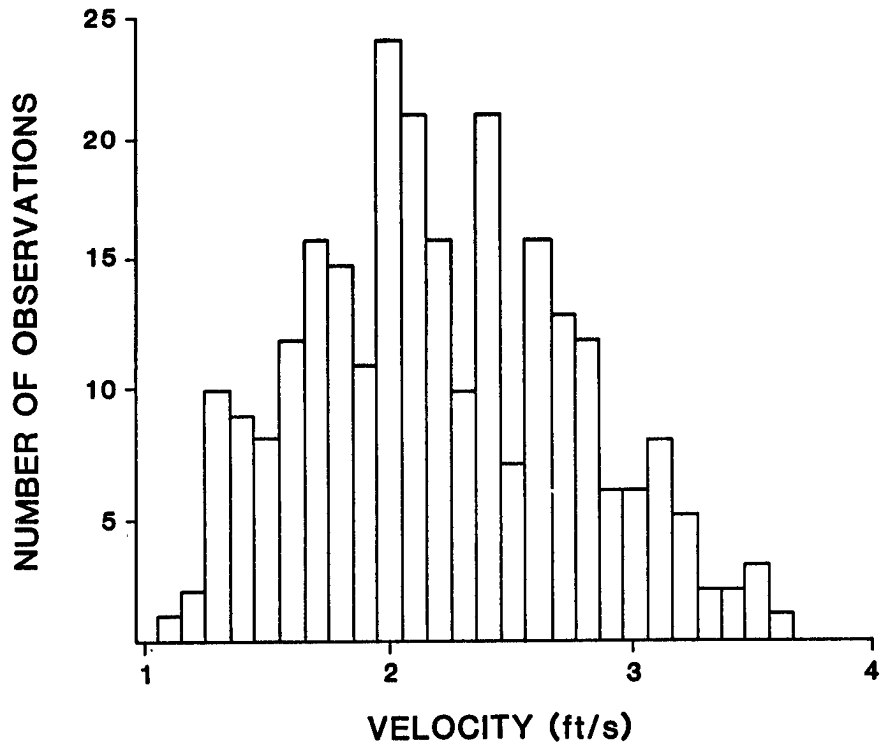

Figure 14. Observed winter steelhead redds for different stream velocities (Hunter 1973, cited in Bovee and Cochnauer 1977).

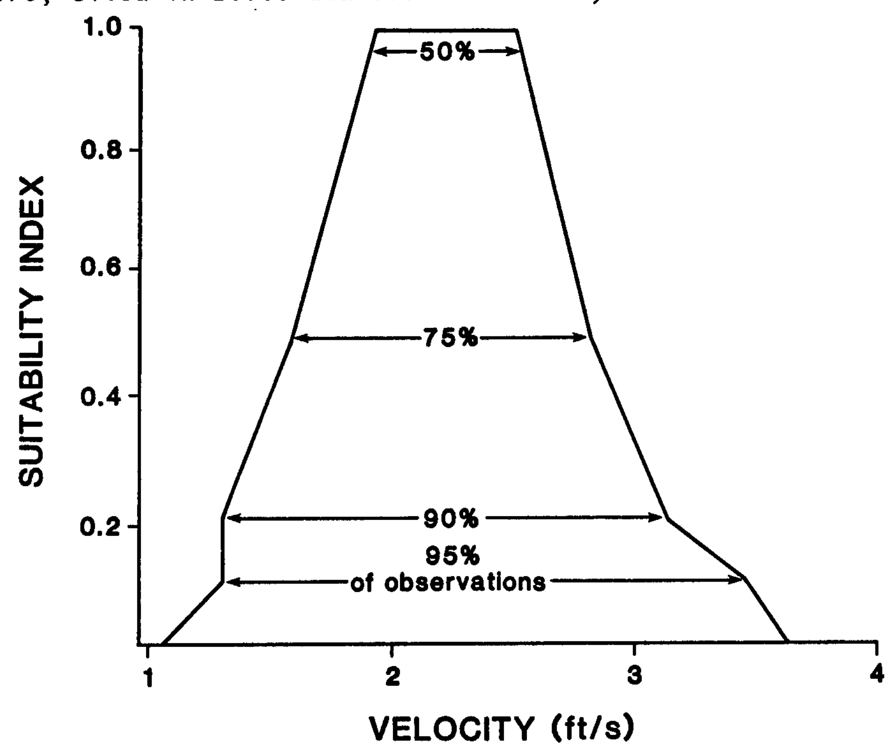

Figure 15. Suitability curve derived by nonparametric tolerance interval analysis of steelhead data from Figure 14. See text for details of curve construction.

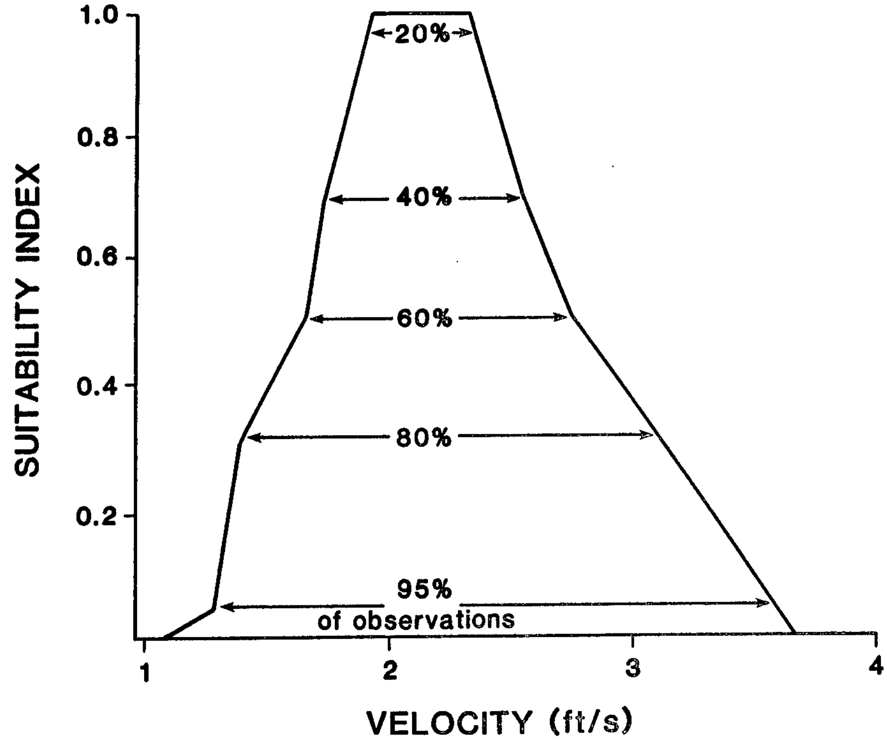

Figure 16. Suitability curve derived by nonparametric tolerance interval analysis of steelhead data from Figure 14. See text for details of curve construction.

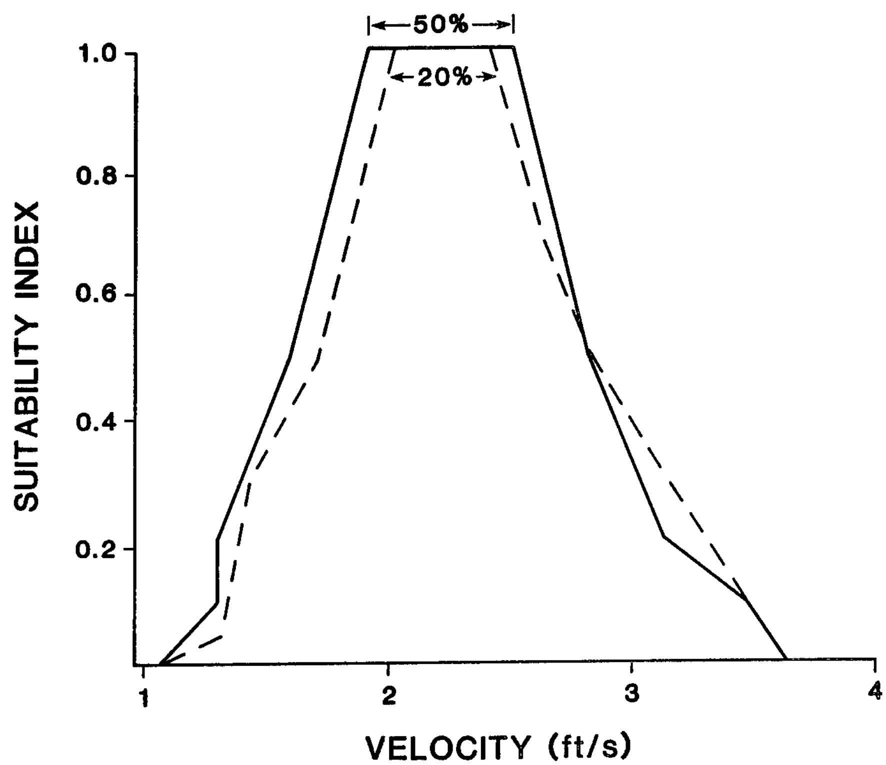

Figure 17. Suitability curves of Figures 15 and 16, superimposed.

nonparametric tolerance curves plotted together. Notice that the curves are not very different even though one curve assigns a suitability of 1.0 to the central 20 percent and the other to the central 50 percent. This is because the central 20 or 50 percent of the data may end in the same bin or adjacent bins along the microhabitat variable.

In the examples just given (Figure 17), the 90 percent confidence level was chosen; however, if other confidence levels are chosen (e.g., 95 or 75 percent), the resulting suitability indices differ little from the ones already shown. This and the similarity of the curves that assign a suitability of one to the central 50 or 20 percent of the population (Figure 17) perhaps should lead us not to give much weight to the statistical evaluation of these curves.

The nonparametric tolerance curves presented so far were constructed for data that are roughly unimodal. For monotonic data, e.g., the response of Dolly Varden to velocity (Figure 6), it would be inappropriate to assign a suitability index of 1.0 to the central 50 percent of the data because the highest suitability is found on the edge. To apply the nonparametric tolerance method to such data a suitability of 1.0 should be assigned to the left most (or right most) 50 percent of the data, and so on. That is, the method should be applied in a one- rather than two-tailed way.

Some of the advantages of the nonparametric tolerance interval method for constructing suitability curves have already been mentioned. It is free from assumptions about the distribution of the data and resistent to the influence of outliers. In addition, it is easy to compute, never gives bimodal results (even when the data are distinctly bimodal), and properly deals with the edges of the data if the appropriate one- or two-tailed version is used. In frequency and regression analysis many details of the analysis are left to the investigator, and choice of these details strongly influences the final shape of the suitability curve. In contrast, this method seems to give strikingly similar curves no matter what confidence level or percent of the population is covered at each step.

Disadvantages of the nonparametric tolerance method include its possible misuse. For example, a curve will result for random data or a flat species response distribution. Therefore, prior testing to see if species response varies over the microhabitat variable is important. The method is only appropriate for count or frequency data; it cannot be used for biomass or density measures of response to habitat. Further, it cannot be used with relative frequencies unless these can be converted back to raw frequencies. For this reason, constructing curves from published data may not be possible unless the sample size is known. A last disadvantage is that there is no way to scale a nonparametric tolerance curve to make it commensurate with the raw data, therefore residuals cannot be computed and used to evaluate the curve.

RUNNING FILTERS

Consider again the Dolly Varden versus depth data (Figure 2). These data may be taken to represent a signal concerning the response of Dolly Varden to depth. The signal, however, is accompanied by noise; thus the task of

constructing a suitability curve is to separate the signal from the noise. In this example the signal is the overall pattern of few fish at shallow depths, many fish at intermediate depths, and few fish again at greater depths. That is, the signal has a low frequency ("frequency" is used here not as a proportion but as the cyclic change in y-axis values per x-axis unit), whereas the noise is associated with the relatively high frequency jitter from interval to interval along the x-axis. To construct a suitability curve from these data the high frequencies need to be filtered out leaving the low frequency signal.

The curve construction technique of frequency analysis aggregates adjacent bars so that the high frequency noise is averaged out. Now consider a similar way to average out high frequency jitter. Assume as usual that the count (or biomass or density) data are arranged according to values of the habitat variable. First, replace the second species response value with the average of the first three values. This is the same as replacing the first three bars in frequency analysis with a wide bar centered over the midpoint of the first three intervals. Next, replace the third value with the average of values two, three, and four, then replace the fourth value with the average of values three, four, and five, and so on. Since the first and last data points can not be averaged in with values from either side, they can retain their original y-axis values (but see below).

This is a running mean filter with a span (or window) of three. It is different from frequency analysis using a span or interval width of three in that each data point contributes to the placement of three points along the x-axis rather than contributing to a single point (bar); correspondingly, rather than three, only one final plot is produced. The result is much like superimposing all three bar plots derived in frequency analysis onto a single plot.

A first modification to make to this method, when averaging three points, is to give more weight to the middle point. Often the middle point gets assigned twice the weight of the edge points. For example, the value of point two would be one fourth the sum of value one, value two, value two again, and value three (this is algebraically equivalent to applying a running mean of two points twice). Figure 18 shows the result of applying a three point weighted average filter to the Dolly Varden data. In frequency analysis, if aggregating on intervals of three does not produce a more or less smooth curve then wider aggregation is necessary, but in this technique the three point filter can be reapplied to the first result (or first smooth) to get a second smooth (Figure 19).

With this introduction to running means other possibilities become obvious. The window size can be increased giving running mean (weighted or unweighted) filters of 4, 5, 7, or more points. Generally, the larger windows give globally smooth curves, whereas smaller windows reflect local fluctuations in the data. Large windows filter outliers more efficiently and can reduce the effect of two or more outliers in a row. Small windows preserve detail in the data that may be important, but may stray towards a few odd points.

Instead of giving more examples of running mean filters the subject is advanced by considering another modification that has even more resistance to

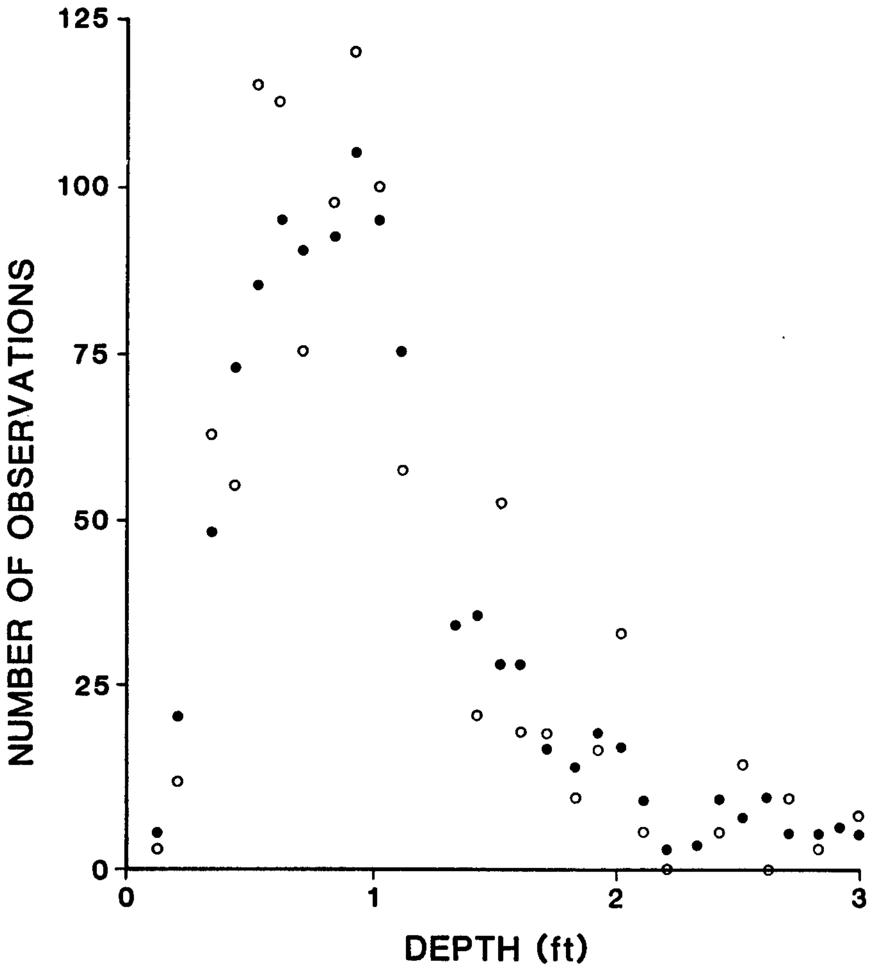

Figure 18. Response of Dolly Varden to depth (open circles) and the results of a three-point weighted average filter (closed circles).

outliers and is easier to compute. The average or arithmetic mean is well known to be influenced by extreme values, giving a misleading indication of central tendency. The median, or middle value of a set of data, on the other hand takes into account the presence of outliers but is not influenced by their actual values. Accordingly, running medians can be used to smooth data infested with odd values and often do a good job of recovering the signal from the noise. Of course, running medians of various spans are possible, but odd-numbered spans simplify computation (the median of an even-numbered group is the mean of the middle two values). As with running means the result of one smoothing operation can be smoothed again by the same or a different filter.

The repeated application of various running smoothers is called a compound smoother or compound filter. One such compound filter that has proven successful on a wide variety of data stems from the work of Tukey (1977). It is described in Velleman and Hoaglin (1981) and compared to other smoothers in Velleman (1980). It is also available in some computer packages including the newer versions of MINITAB (release 81.1 and later) and SYSTAT. The data are

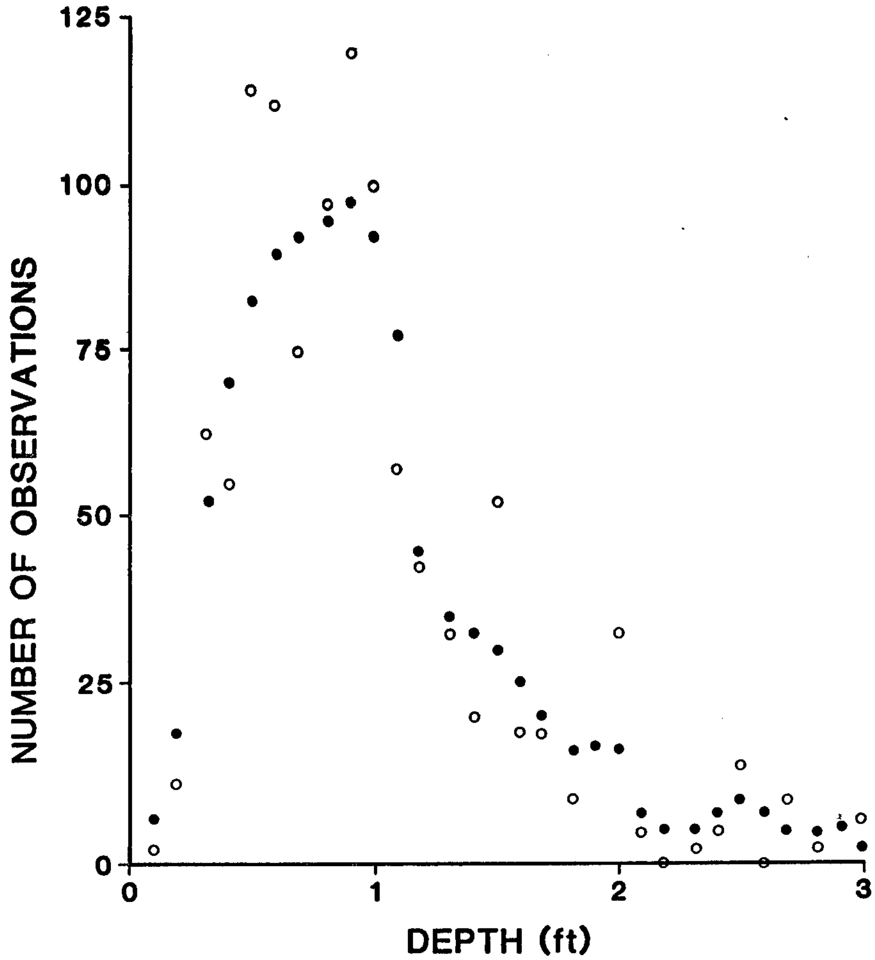

Figure 19. Response of Dolly Varden to depth (open circles) and the results of a three-point weighted average filter applied to the smoothed points shown in Figure 18.

first smoothed by applying a succession of running median smoothers of different spans (four, followed by two, then five, then three). This serves to filter outliers and smooth chance periodicities in the data that can distort the results of other smoothers. Then the last median smooth is polished by a running weighted mean of width three.

The result of applying this five-part compound smoother to the Dolly Varden versus depth data is given in Figure 20. The smooth generally resembles other summaries of this data that were judged acceptable. It does not have the corners resulting from connecting the midpoints of the bars given by frequency analysis; it has a similar intercept, is slightly narrower in the peak than the fifth degree polynomial, and shows only a slight rise in the right-hand tail rather than the distinct secondary mode of the regression curve. It is also narrower than the curve given by the nonparametric tolerance technique and is more concave than that curve. The original data, also shown in the figure, typically lie close to the smooth curve throughout.

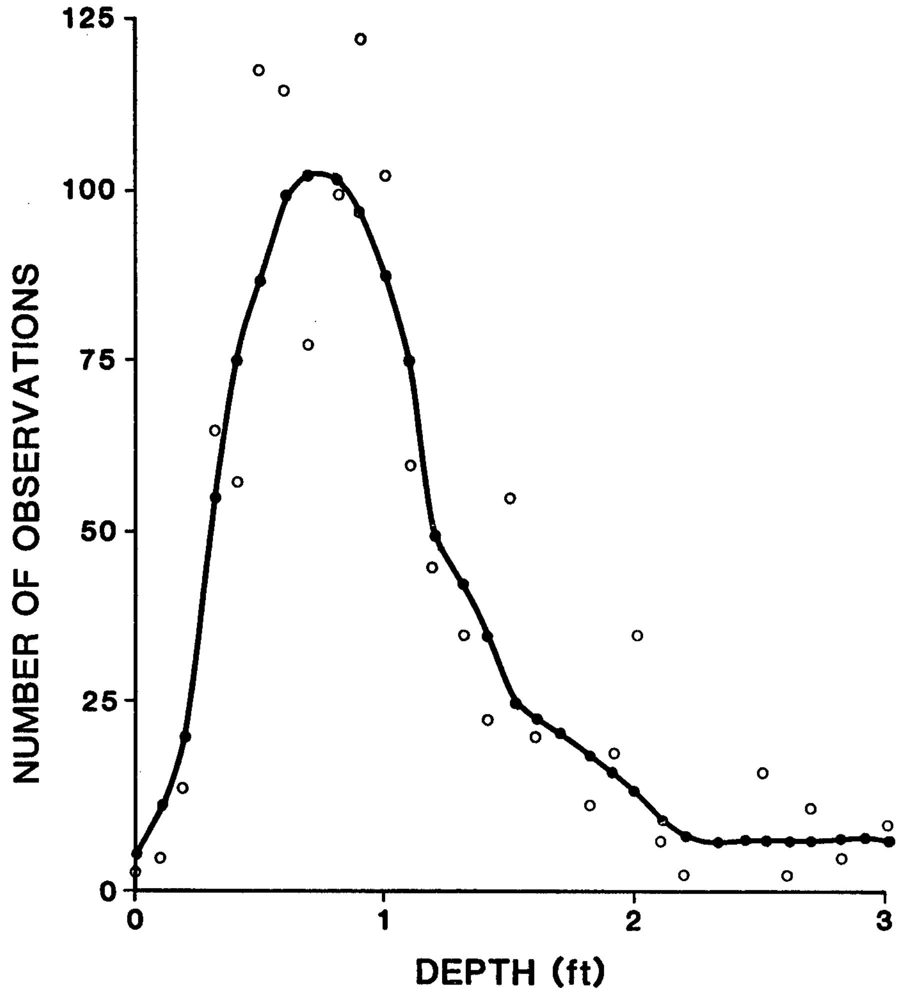

Figure 20. Response of Dolly Varden to depth (open circles) and the results (closed circles) of applying the five-part compound smoother described in the text.

For all running filters, the end points need special attention because they do not have neighboring points on one side. Running filters with a window of three do not define the first and last points in the series. Running filters with a window of seven leave three undefined points at each end. For the wider span smoothers, all but the end points may be smoothed by narrowing the window near the edges (Tukey 1977). To smooth the remaining end points the simplest remedy is to use the original, unsmoothed points to define the ends of the smoothed curve. It also may be acceptable, depending on the data, to sketch a smooth continuation of the filtered curve to the edges.

A more objective way (Velleman and Hoaglin 1981) to estimate the first and last end points is cumbersome to explain but easy to do. The end point is estimated as the median y-value of three points. These are the raw end value, the smoothed value second from the end, and the value of a point extrapolated on a straight line connecting the second and third smoothed points from the end. The y-value of the third point is taken from the extrapolated line above the x-axis position corresponding to one point beyond the first or last point

on the x-axis. This technique is illustrated in Figure 21. When running filters are applied successively to smooth a data plot or a compound filter is used, the end point procedure need only be applied at the last step.

The procedure of end point estimation has another use. Running median filters, when repeated, often result in a stable curve with plateaus, steps, or valleys two or more points wide. These flat segments can be rounded by applying the end point rules to reevaluate the corners of these segments.

A last general point about running filters is that when spans are even numbers, the estimated or smoothed point falls between original x-axis positions. For example, a running mean of two points results in a y-value plotted midway between the first two x-axis values. It is customary to apply another filter with an even span to recenter the smoothed values over the original x-axis positions. This is why, in the compound filter described above, running medians of four points are followed by running medians of two points.

Disadvantages of running smoothers stem in part from their variety, for, again, it is up to the investigator to choose what is appropriate for the data under analysis; different investigators may come to different conclusions. Running mean smoothers are influenced by outliers, though not to the extreme of regression. Wide-span running means trim outliers, but may overround sharp turns, peaks, or drops in the data. Narrow-span running means follow the data closely, but may track extreme values too closely. The only restriction on data subjected to running filters is that the x-axis values be more or less equally spaced. Most data used to construct suitability curves will meet this requirement, except perhaps in the tails, and some relaxation of the requirement is permissible (McNeil 1977; Velleman 1980).

The five-part compound smoother given above generally gives good results, but as with the other filters, there is no statistical measure of how good the smooth fits the data. There is also the problem of oversmoothing that can result when the data are repeatedly smoothed. To be able to reapply a smoother is often an advantage, but comes at the cost of having no clear criteria for when to quit.

Advantages of running filters for constructing suitability curves include their ease of computation and (somewhat limited) availability on computers. As in frequency analysis and nonparametric tolerance methods, running filters are free of statistical assumptions about the data. Unlike these methods, but as in regression, calculation and analysis of residuals are straightforward. Unlike regression, however, running filters are not overly influenced by outliers and tend not to produce spurious modes, tails, or negative values. The five-part compound smoother described above is perhaps the best smoother among the running filters for species response data and is as good or better than the other techniques presented for constructing suitability curves.

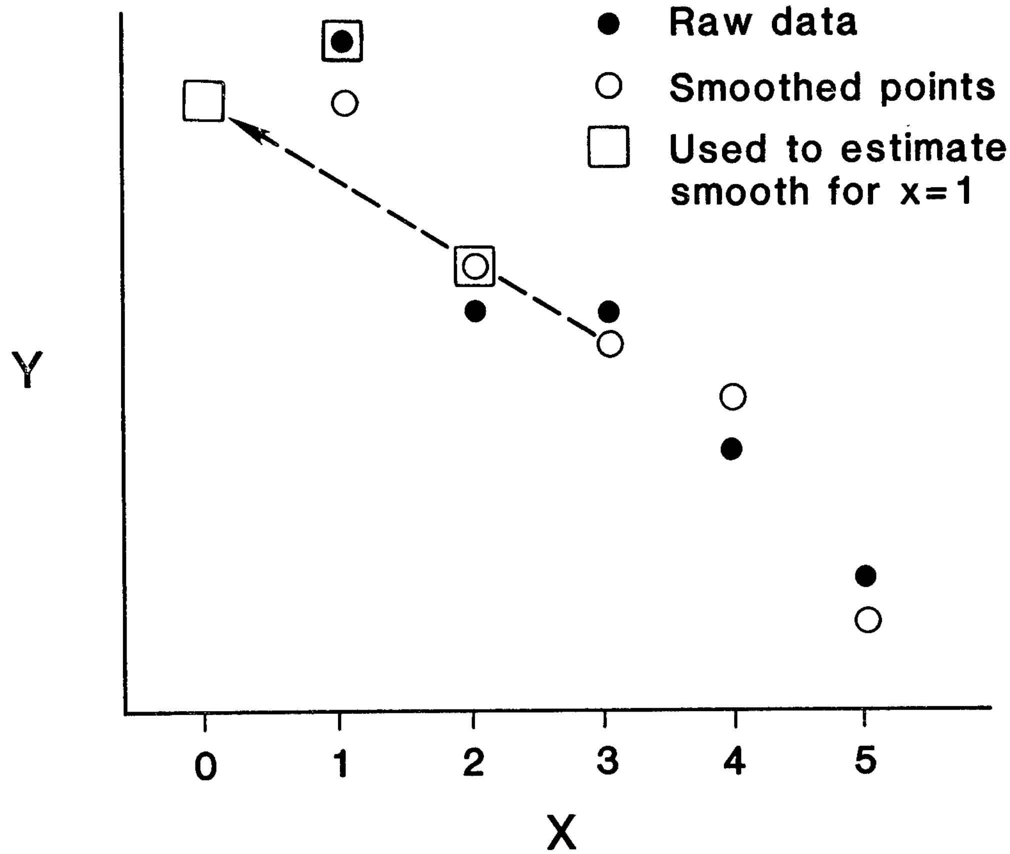

Figure 21. Application of the end point procedure. Raw data are closed circles and smoothed points are open circles. The estimated value to place at x = 1 is the median of the three points in boxes. In this case the median is the point projected above x = 0 on a straight line connecting the smoothed values for x = 2 and x = 3.

SPECIAL TREATMENT OF THE DATA

Suitability curves may be improved if some adjustments are made to the data prior to analysis. These adjustments typically will not affect the results of frequency analysis or nonparametric tolerance analysis, but can influence regression and filter analysis.

If either tail of the species response curve comes down close to the x-axis and the investigator believes that the limiting values of the environment are being approached, then response values of 0.0 can be added to the data for a few x-axis positions beyond the tail. For the steelhead versus velocity data (Figure 14) values of 0.0 could be added for velocities of 0.5 to 1.0 and 3.7 to 4.0 feet per second. This addition ties the curve down at the tails, gives regression more "data" points to help smooth out rising

tails, and overcomes the need to use special end point rules for running filters.

In a similar way a species response value of 0.0 can be added to depth curves for depth equal to 0. This may be appropriate even if the left side of the depth curve is high above the x-axis.

Species response values of zero also may be legitimately removed from the data before analysis. Positive y-values indicate that the corresponding environment is not limiting to the organism; zero values, however, are ambiguous. Sometimes zero values indicate that the environment is limiting, but they may also occur along the x-axis within the tolerance limits of the organism, indicating only the lack of a sample or observation from a particular environment or that some other factor prevented the organism from occurring. For example, in the Dolly Varden versus depth data (Figure 2) no fish were observed at depths of 2.2 and 2.6 feet.

If such zero values misrepresent a species' response to environment they might well be removed before performing any analysis. Regression analysis probably benefits the most from this modification. Running median filters of three or more points are less affected, since many zero values are apt to be filtered out anyway. Notice that frequency analysis is forced to include any ambiguous zero values and that nonparametric tolerance analysis is forced to exclude them. In the last two methods the investigator has no choice concerning ambiguous zero values, whereas in regression and filter analysis the choice is there to be made.

Transformation of raw data before analysis is common in statistical analysis. In data used for constructing suitability curves it is often the case that large response or abundance values are associated with a large variance and small values with a small variance. Consider sampling for the response of a given species over an environmental variable. Suppose 100 individuals are found in the region of maximum occurrence, say at a depth of 2.0 feet, and two individuals are found in a region of low occurrence, say at a depth of 6.0 feet. Now a resample might well find 85 or 115 individuals at 2.0 feet deep (a difference of 30), but perhaps only 8 or 10 or even no occurrences at 6.0 feet will be found. Logarithmic transformation is the usual remedy when the variance changes in this way (Sokal and Rohlf 1981). To avoid taking the logarithm of 0.0, 1.0 is added to each raw value before transformation. After the transformed data are smoothed they are back transformed and scaled 0.0 to 1.0 to produce a final suitability curve.

The logarithmic transformation is most appropriate when regression is used to produce a suitability curve. Frequency analysis and running median filters will give the same results as when applied to the raw data so long as the final curve is transformed back to original arithmetic units. Running mean filters or compound filters that include a mean will give different final curves when applied to raw and transformed data. Nonparametric tolerance interval analysis cannot be applied to transformed data.

All the curve-smoothing techniques described above were presented as if there were a single y-value for each x-value. This will always be the case for frequency or count data, but when the measure of species response to

environment is density, biomass, or some other quantitative measure, then there usually will be several y-values for a given x-axis position. Regression analysis is the only technique, among those given above, that can be directly applied to such data (type II regression, Sokal and Rohlf 1981). To apply the other techniques (or type I regression) the several y-values for each x-value need to be reduced to a single value. The obvious solution is to average the several y-values, but taking the median of the y-values for each x-value might also be fitting and serve to eliminate extreme values in the earliest stage of analysis.

Reducing multiple y-values for each x-value to a single number becomes more complicated if a logarithmic transformation is used. There are two possibilities. The mean can be taken before or after the transformation. If the mean is taken before transformation, outliers will have more influence. If the mean of the logarithms of the raw values is taken, then the back-transformed value will be the geometric mean of the raw values. The latter procedure is recommended, but only because the leverage of extreme values is reduced.

Frequency analysis and running filters can only be applied to data that have a single y-value for each x-value. Therefore, to apply these methods to density or biomass measures the data must first be averaged or transformed and then averaged as described above. Regression analysis can be applied to data that have been thus changed, but at the cost of ignoring one source of variance (the variance associated with each x-value). Nonparametric tolerance interval analysis cannot be applied to quantitative data.

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QUESTION AND ANSWER SESSION

Bill Slauson

Barrett: I have a couple of comments. First, all this sounds pleasant, but in the end we're going to have to differentiate between statistical significance and biological significance. I think you touched on this, but in the end, does it matter to the fish? We've got these dips and grooves (in the data), you can have filters on both ends, but I don't think a trout is going to care. It's suitability is not going to drop between 3 feet and 3½ feet, and go back up at 4 feet. You have to be aware of that. The other thing is that I think the cumulative distribution function does have some utility. It's nice to use when comparing abnormal distributions. The only assumption is that the data were collected randomly. The cumulative frequency has a little more utility than it is given credit for.

Slauson: I didn't criticize using a cumulative distribution function, but rather doing a regression on one. In the last couple of days, we've seen lots of suitability curves put up here. Some of them real, some of them just drawn in to represent any curve. None of them, that I remember, was Gaussian. I didn't see a normal-looking curve in the bunch.

Smith: I've used the five-part filter in Mini-Tab. I've had some problems out on the right-hand limb where you have few observations. It tends to drop out those observations when it produces a curve. That is, in cells with no observations, you may have problems.

Slauson: I should say that these filters assume that you have equally spaced x-values, or nearly equally spaced. You could have one or more data gaps out on the tails where one interval has zero occurrence, the next has one fish, then zero, then one.

Smith: Yes, when that starts happening, the running filter tends to drop out those last observations.

Slauson: One solution is to put in zeros as real data, out on either tail to help stabilize the tail.

Voos: Can you apply any of these techniques to developing suitability functions with the correction for availability? I mean, it seems like you're always talking about the number of observations as utilization data.

Slauson: Yes, the reason I've used the number of observations is because the sample data I've picked to present these methods happens to be utilization data. Of course, it would work with availability data as well.

Voos: It would for availability data, but how would you produce a category III curve? Here, you are not dealing with raw frequencies anymore, but rather, with ratios.

Slauson: I don't know, I haven't thought about that. But, most of the methods I discuss are not restricted to frequency data.

Lifton: One of the inherent assumptions that we seem to be using here is that we're dealing with one population of data each time we draw a curve. Very often your utilization data actually reflects several populations. Perhaps it is an interactive behavior between depth selection and different covers or substrates. By assuming all the data are from the same population, we tend to eliminate information by assuming that it is noise within the curve.

Slauson: I think you're right, but I'm talking about methods. I'm assuming that the data are good or the biologists have already decided if a curve comes out to be bimodal, it's really bimodal, and they have determined the reason for it.

Lifton: Have you considered harmonic or Fourier analysis?

Slauson: Just a little bit. But there is a limit to the number of techniques I could investigate.

Lifton: You could still fit it?

Slauson: You could fit it and it might be worth a try.

Li: Could you explain you notation of 0.9 on the tolerance limits curves? Is that actually a top level of 0.1? I don't know what your 0.9 stands for.

Slauson: The 0.9 refers to the 90% confidence level. The table in Information Paper #21 contains values for the confidence levels from 0.75 up to 0.9.

Bovee: Ken Voos brought up a point that I had never thought of before. In Information Paper #21, I suggest that you should probably make the correction for availability off of a smooth curve for both utilization and for availability. It just occurred to me that if you had a distribution like some of those you've shown, with a little wiggle in the distribution, you probably would not want to smooth the curve until you were all done.

Slauson: It's hard to know. For biological reasons you can think that species' responses should be globally smooth. But I don't know if there is any reason to think that the environment should be distributed in a globally smooth way. There could be irregularities in availability just because of the shape of the channel or whatever.

Bovee: Have Wayne Lifton and Ken Voos had any experience with that? Have you run into problems with smoothing or anything?

Lifton: You'll see some examples.

Hanson: I have a similar concern. I agree with Wayne's comment that you may have different populations. Some of the apparent bimodality in the data may be real, indicating that you should stratify your data before you start trying to make a modified function. Another disadvantage that I thought of in regards

to curve fitting (i.e., regression--eds.) is when you're fitting curves rather than using smoothing techniques or non-parametric tolerances, you're assuming a particular distribution; you're assuming that a given equation is the correct equation. You don't really know whether the equation that you selected is the correct one, whether it's a polynomial equation, quadratic, or whatever. The model is finding the best coefficients for the equation you selected. So you're implying a given equation or shape to your data, unlike some of these other methods that are distribution-free.

Slauson: Can you think of any biological reason that a species is going to respond to a function of depth, depth squared, and depth cubed?

Hanson: No.

Slauson: It's just an artifact that lets you draw a line through a set of data.

Lifton: If you look at a wide range of multivariate statistics on environmental data, generally, you're in a position where you have to transform these with either a square root transformation, maximum standardization, or logrithmic transformation, and generally you'd expect response to environmental variables to be nonlinear.

Slauson: That doesn't mean you know what nonlinear functions to use.

Lifton: True, but at least when you're function fitting, you have the advantage of having a measure of fit.

Slauson: That's right. One final thing, these are often called category II criteria. Every method I talked about emphasized all the decisions the investigator has to make and maybe these curves should be called category I and 1/2. Still there are all kinds of biological judgments that have to go into them.

AN EVALUATION OF THE EFFECTS OF VARIOUS SMOOTHING AND CURVE-FITTING TECHNIQUES ON THE ACCURACY OF SUITABILITY FUNCTIONS

by

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INTRODUCTION

A number of methods are available for fitting curves or functions to species habitat utilization data. These curves are usually developed on the basis of field observations. Each observation of a specific individual is accompanied by measurements of depth, mean column velocity, nose velocity, etc. These data are summarized, generally in the form of frequency histograms, and used to develop suitability of use (SI) curves. Changes in the position of the curve (i.e., shifts to the right or left) have potentially significant effects on the shape of any resulting weighted usable area (WUA) curve and any management decision based on this curve, especially if the stream under analysis has depths and velocities in a range where suitability changes rapidly. Such shifts are common as one examines different species and life stages, necessitating the development of separate WUA curves for each species and life stage under consideration.

Shifts may also result from an investigator's attempt to determine the true, or most appropriate, shape of a given curve. Morhardt (1986) has demonstrated that the SI curve can be influenced by the choice of interval (bin) sizes used in constructing the frequency histograms from the original data. The changes in the shape of the SI function introduced by the techniques used to establish the curve have not been rigorously evaluated. It is possible that certain curve-fitting techniques lead to greater error about the fitted

curve than others. To investigate this issue, we propose the following approach. Define a theoretical habitat utilization curve, create a population on the basis of this utilization curve, simulate a random sampling of the theoretical population to obtain a data set, evaluate the sample data set with several curve-fitting techniques, determine the error between the derived curve and the known curve, and assess the relative accuracy of the techniques investigated.

METHODS

To define a theoretical utilization curve, we chose a function that approximated a real-life SI curve. Bovee (1986, Appendix C) gives the equations of some functions commonly encountered in the development of habitat suitability criteria. A generalized Poisson density function was used to produce a curve of habitat suitability vs. mean water column velocity for theoretical "rainbow trout fry"; this was patterned after actual data curves presented by Raleigh et al. (1984). The functional form of a generalized Poisson density function (from Bovee 1986) is given by:

$$SI = f(x, a, b, c, d) = [b-x/b-a]^{c} \times e^{(c/d) \times [1 - (b-x/b-a)^{d}]} \qquad (1)$$

where a = value of x where f(x) equals 1.0 = 0 fps

b = value of x where f(X) equals 0.0 = 3.0 fps

c = shape parameter for part of curve to the right of x equals 0 = 8.61

d = shape parameter for part of curve to the left of x equals 0 = 3

e = base of the natural logarithm = 2.71828.

Figure 1 shows the resulting velocity suitability index curve, which is used as the known parent distribution or "true curve" in the remainder of this analysis.

The theoretical SI curve in Figure 1 represents a normalized frequency of occurrence; that is, the number of individuals found within any given velocity interval is divided by the largest observed frequency. Assuming that the correction for availability is insignificant (i.e., all velocities are essentially unlimited so that each individual may occupy water at its preferred velocity), it is possible to determine the number of individuals within a population that are found at each velocity.

The theoretical SI curve (Figure 1) was used to determine the relative frequency for each of 300 velocity intervals, increasing by 0.01 fps from 0 to 3.0 fps. A maximum N of 100 individuals was arbitrarily chosen for SI = 1.0 (at v = 0). The relative frequency (SI) for each of the 300 intervals was

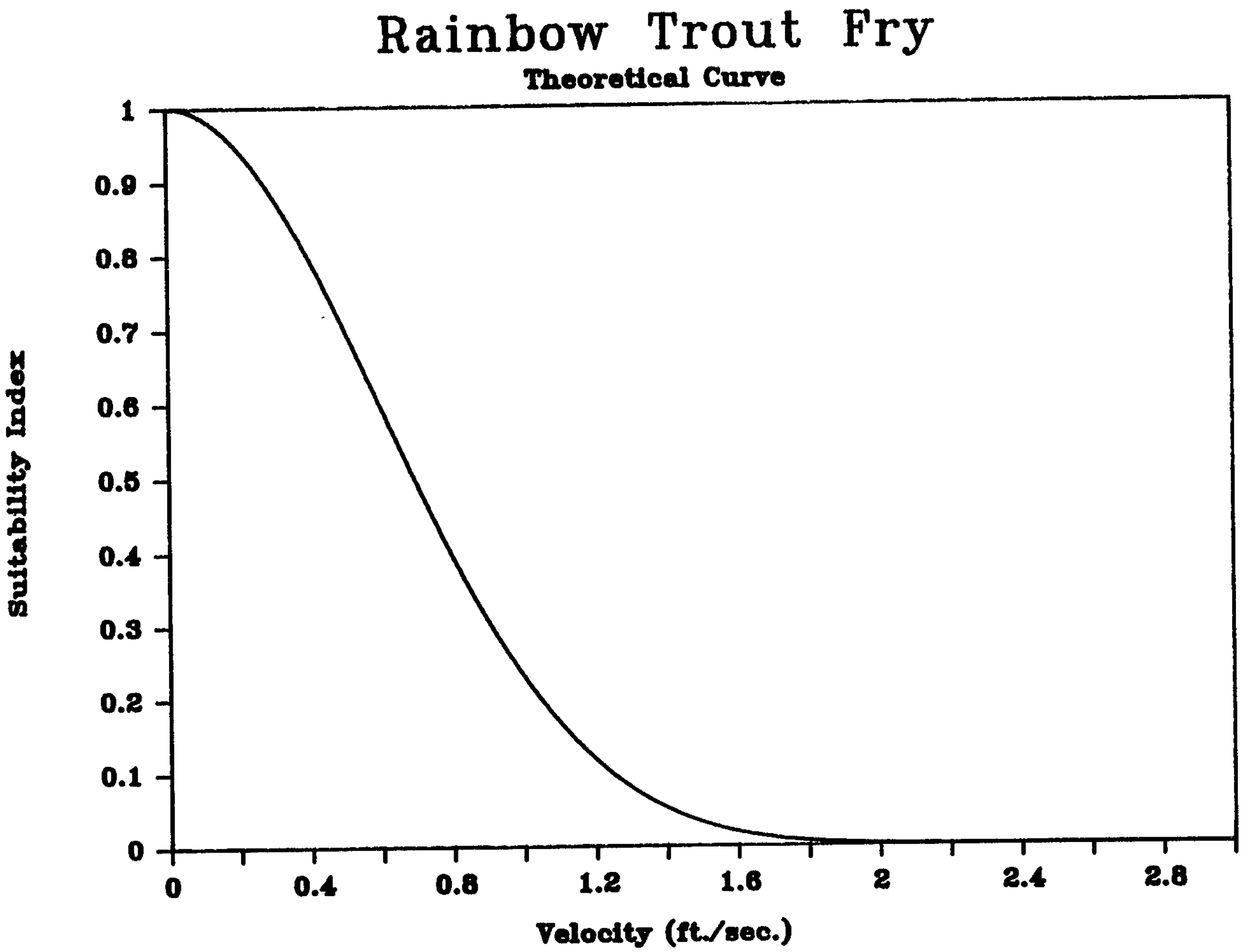


Figure 1. The theoretical curve of suitability versus velocity for rainbow trout fry used as the parent (known) distribution.

then multiplied by 100 to establish the number of individuals of the population in that interval. The total fry population size obtained in this manner was 7,348, a figure that is representative of population sizes found in 2.5 to 8 miles of average high-elevation Sierra Nevada stream habitat during normal water years. The individuals were then numbered sequentially (rounding each fraction upwards to the nearest integer value), each having a particular velocity interval associated with it.

With each individual sequentially numbered, it is possible to take a random sample from this "population." Lotus 1-2-3 was used to construct a spreadsheet. The Lotus software contains a random number generator, which was used to select 200 integers at random in the interval from 1 to 7,348. Once selected, these random numbers were arranged in ascending order, and the associated velocity interval of each was identified. In this way, we simulated the process of collecting 200 random observations of individual fry from a population and measuring the average column velocity associated with that individual. Given this sample, it is possible to analyze the data using various curve-smoothing techniques.

The first step in any of these techniques is to construct a frequency histogram from the data. Lotus 1-2-3 was used to construct histograms from the 200 random observations. An interval (bin) size (some number in hundredths of a foot per second) was specified, leading to the establishment of n intervals, and a macro (a series of instructions controlling specific 1-2-3 operations) was then invoked, which determined the number of observations (frequency) within each interval. The principal advantage of this type of approach is that the parent distribution is actually known. As these data are treated with various techniques to yield an estimate of the actual (parent) SI curve, it is possible to assess the error associated with each estimate. To measure error we turn to a parameter commonly used in fitting statistical curves to data--the sum of the squared deviations between the observed points and the actual curve (Steel and Torrie 1980). That is,

$$Rj = \sum_{i=1}^{n} (Yi,o - Yi,a)^2 \qquad (2)$$

where Rj = the residual error obtained during the jth application of a given smoothing technique (e.g., bin size, number of passes, probability level, etc.) that is applied to the randomly sampled subset of the population

Yi,o = the suitability index value associated with the midpoint of the ith interval of the curve based on the "observed," randomly sampled data

Yi,a = the suitability index value from the actual parent distribution associated with the midpoint of the ith interval

When this criterion is applied to linear regressions, an equation that minimizes the residual error may be determined (least-squares technique; Steel and Torrie 1980). In a similar vein, we will be analyzing the various techniques of curve smoothing to evaluate which one minimizes the residual error as defined in Equation 2. This approach of minimizing the residual error is also essentially the same as those used in fitting nonlinear curves to histograms (see Bovee 1986, pp. 132-143).

RESULTS AND DISCUSSION

A variety of techniques may be applied to raw data to construct a continuous utilization or preference curve. Bovee (1986) and Morhardt (1986) present reviews and discussions of these techniques. Bovee (1986) identifies three basic categories into which these smoothing techniques can be placed: histogram analysis, nonparametric tolerance limits, and function fitting. Most of the analyses used to develop habitat suitability criteria use a technique in one of the first two categories. That is, univariate and multivariate function fitting is not often used to develop suitability curves.

Notable exceptions to this are Voos (1981) and Hanson (1987). Even here, however, some type of histogram analysis is usually completed to smooth the data prior to curve fitting. Consequently, in this report we have chosen to evaluate histogram analysis and nonparametric tolerance limits with respect to the power of these techniques to minimize the errors between the observed and actual curves.

HISTOGRAM ANALYSIS

Choice of Interval Size

Usually the first step in any type of habitat utilization analysis is to group the observations into intervals and plot the resulting histogram. Morhardt (1986) has already shown that the size of the bin used in constructing these frequency histograms can significantly affect the shape of the resulting SI curve (whether it is fitted by eye or by some statistical technique). He states, however, "that there is no overriding theoretical reason to use one bin size over another. All of them produce equally valid results, but with decreasing information content as bin size is increased."

To test this conclusion we analyzed the effect of constructing frequency histograms with varying bin sizes (Figure 2). The resulting frequencies were converted to a suitability index through normalization (dividing the frequency within each interval by the largest observed frequency). The smallest interval used (0.01) represents the level of resolution at which these data were collected (e.g., the instrument and/or sampling accuracy). At this level of resolution, the histogram is characterized by many peaks and valleys (empty bins). Any curve fitted to these data would retain these same characteristics. Visual comparison of this histogram with the original parent distribution (Figure 1) indicates that most of this behavior is associated with sampling error: variations in the histogram related to under- or overrepresentations of certain intervals that are due to the random sampling process. When an interval size of 0.3 is reached, the frequency histogram begins to take on the basic shape of the parent distribution. As one moves to larger bin sizes the histogram maintains this general shape (high at the origin, decreasing toward higher velocities), but the difference in SI between adjacent bins becomes accentuated. This produces an SI curve that is flat near the origin and then drops very rapidly as velocity increases.

These results have interesting implications. The reduction in "noise" as one moves from the highest level of resolution to an interval of 0.3 implies that there is a bin size that minimizes the effect of random error in the data. Conversely, as one moves toward higher bin sizes, the distortion of the curve implies that too much information has been lost about the shape of the underlying parent distribution. This suggests that there may be an "overriding theoretical reason" to chose one bin size over another when constructing a frequency (SI) histogram. It shows that each choice of interval size does not produce equally valid results.

To place that conclusion on firm theoretical and numerical grounds, we analyzed the residual sum of squares (Equation 2) obtained for each SI

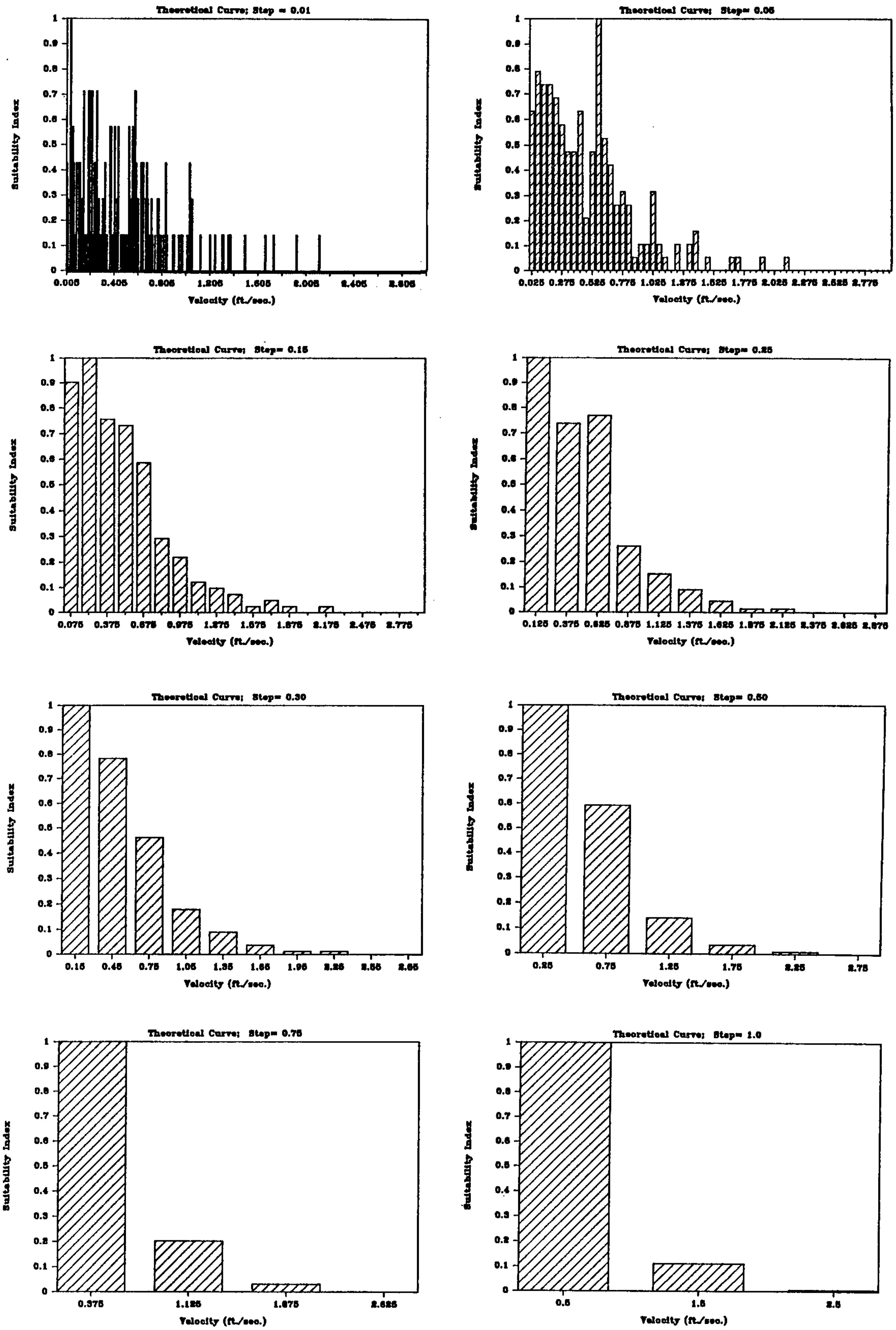


Figure 2. The effect of interval (bin) size on the shape of the resulting suitability histogram. The shape of the histogram will affect the shape of any preference curve based on that histogram.

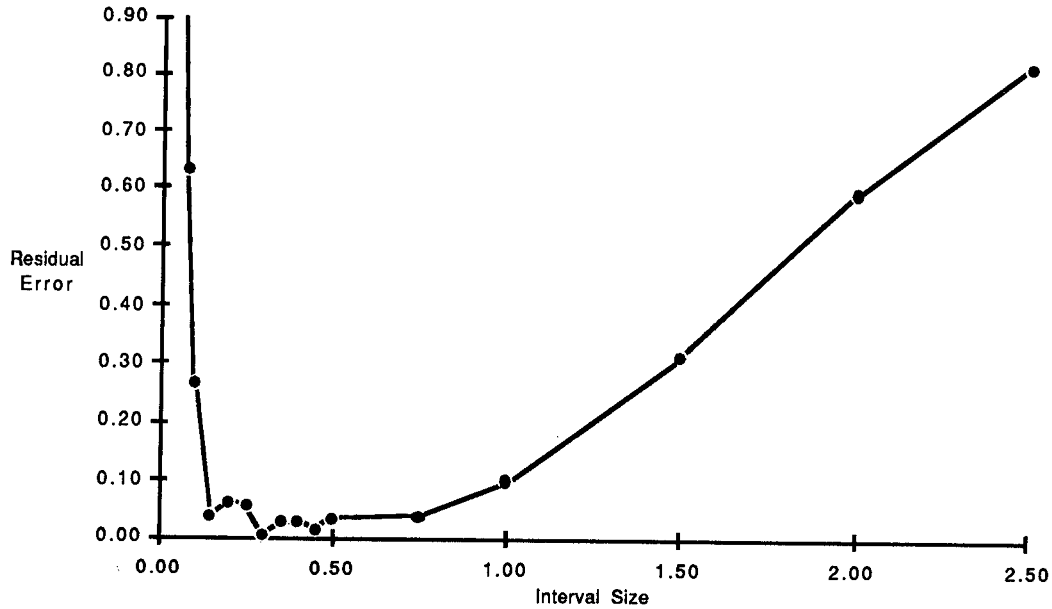
histogram as the bin size was varied. To obtain the residuals we used the midpoint of the velocity interval as the velocity of the parent distribution (Equation 1). An observed and an expected SI were thus obtained; summing across all intervals in the frequency histogram produced the total residual given in Equation 2. Figure 3 shows how the total residual changed as the interval size for each frequency histogram changed. Note the definite minimum in the response curve at an interval size of 0.3; interval sizes less than 0.15 and greater than 0.75 produce significant error (the curve climbing rapidly as bin sizes change).

The large error associated with small intervals (less than 0.15) is attributable to two sources: (1) the effect of random "noise" resulting from sampling error that introduces false peaks and valleys in the distribution, and (2) the increase in the number of intervals in the histograms increases as bin size decreases, causing the number of comparisons between observed and expected values to increase. To remove the influence of the latter effect, we determined the mean residuals by dividing the total error by the number of bins in the histogram. Figure 4 shows the result of this transformation. The basic shape remains the same, but error increases for small and large bin sizes; the minimum at 0.3 remains unchanged. Thus, our conclusions are the same regardless of whether we use total error or mean error as the criterion of comparison. Total residual error is still the preferred choice, however, because it reflects the total error associated with the selection of a given interval size. After removing the effect of the number of comparisons from the error term, we see that substantial error still remains due to the effect of sampling error. The proper choice of interval size c.n significantly reduce this source of error, as is shown by the small total error and mean error associated with an interval size of 0.3.

Comparison of Figures 3 and 4 also shows what is occurring as one moves to larger interval sizes (greater than 0.75). The increase in total error is primarily the result of increasing deviations between the observed and expected SI's. This is most clearly demonstrated in the rapid increase in mean residual error for large intervals (Figure 4). This results from the loss of information about the true form of the parent distribution as data are grouped into larger and larger "summary" bins.

Further inspection of Figures 3 and 4 indicates that for some intervals (greater that 0.15 and less than 0.75) the errors are relatively similar (there is a broad valley in the response curve). This implies that significant improvements in the accuracy of our inferences about the shape of a suitability curve can be obtained if we choose an interval in the neighborhood of the "optimum" interval. The best case, of course, is to choose the interval where error is minimum, but in cases where the parent distribution is unknown this is difficult or impossible. If, however, we can choose an interval that is close to (or in the neighborhood of) the true minimum, error can still be significantly reduced.

A.



B.

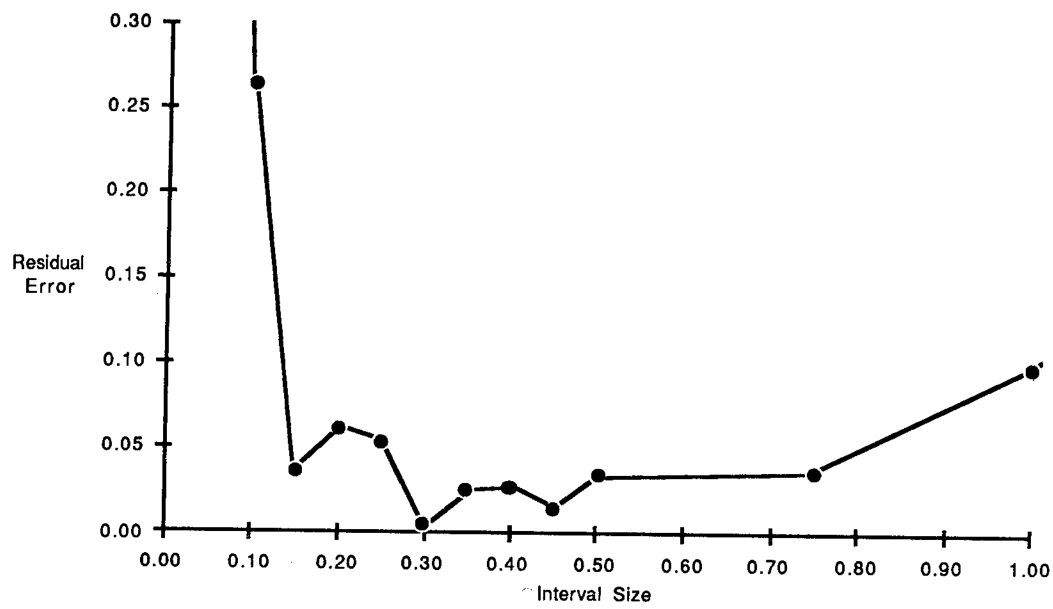


Figure 3. The total residual sum of squares vs. the interval size used to construct the normalized frequency histogram (suitability function): (a) over full range of residuals and interval sizes, (b) over range of minimum residuals, magnified.

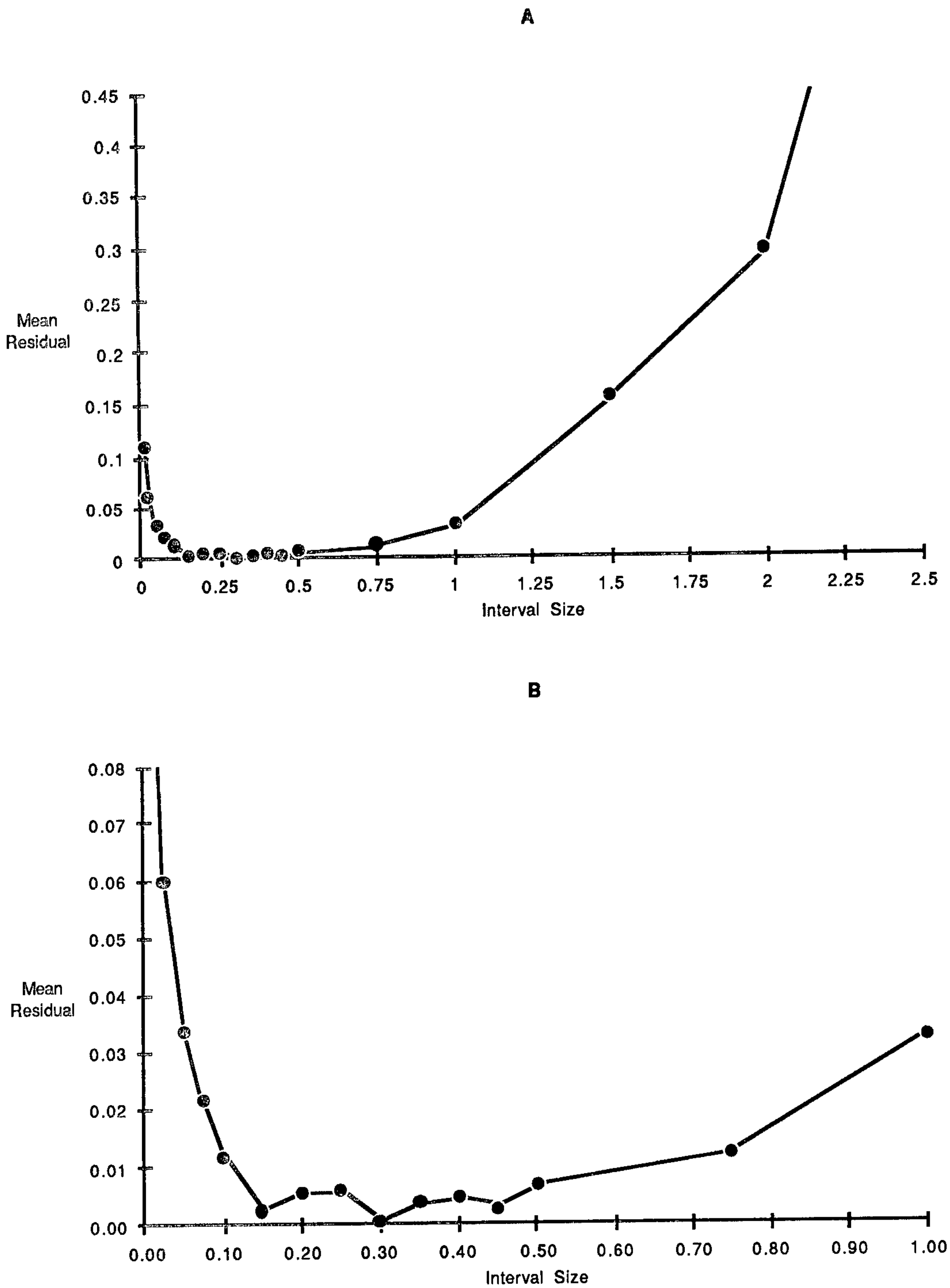


Figure 4. The mean residual sum of squares vs. the interval size used to construct the normalized frequency histogram (suitability function): (a) over full range of mean residuals and interval sizes, (b) over range of minimum mean residuals, magnified.

Sturges (1926) gives an equation for determining the optimal interval size. His equation is

$$C = R/(1 + 3.322 * \log_{10}N) \quad (3)$$

where C = the optimal class (interval) size

R = the range of the variable (Xmax - Xmin)

N = the number of observations

Applying the Sturges equation to our sample, we obtain an estimate of the optimal interval size of C = 0.25, with R = 2.12 (Vmax - Vmin = 2.12 fps - 0 fps) and N = 200. C is rounded off to the nearest 0.01, since this was the resolution of our sample. The estimated C is in the neighborhood of the interval that gave the minimum residual error (0.3). Thus, application of the Sturges equation prior to any further analysis of the data may significantly reduce the error associated with random sampling and information loss.

Note that the range used to calculate C was from the sample. Most applications of the Sturges equation will probably obtain their range estimates in this manner. The range of values observed in our parent distribution is R = 3.0 (3.0 fps - 0 fps). If this were known a priori, it could be used to obtain an estimate of C. Recalculation of C using the parent distribution range gave an estimate of optimal interval size of C = 0.35. The two estimates of C bracket the observed optimum interval of 0.30. Since the range of the parent distribution is usually unknown, and it is highly improbable that it has been observed in sampling (by definition, few individuals are found at these extremes), it is infeasible to use it as a predictor of C. However, these results do suggest that judicious use of the known tolerance range of a species to estimate R, not just sampled data, might improve the estimate of C. For example, Raleigh et al. (1984) calculated weighted mean frequencies of fry observed at various column velocities. The highest velocity where fish were observed was 2.46 fps. Using this value in our range calculation resulted in an estimated optimal interval size of C = 0.28. Since using the known (published) range of a species improves the estimate of C, we suggest that estimates of the range should come from all available data, not just the sample in hand.

In an attempt to improve the estimation capability of the Sturges equation (Equation 3) we estimated a new value for the coefficient of the $\text{Log}_{10}N$ term. Further investigation into the theoretical basis of the Sturges equation indicated that such a correction was unjustified. Sturges' definition of optimum was based on enumerating the characteristics of normally distributed variables (means, variances, skewness, etc.). No consideration of residual error, minimizing the effect of random noise or controlling the loss of information about the shape of the curve was considered. Consequently, the Sturges equation should be viewed as a guideline to selecting appropriate interval sizes; the estimation of the true optimum size from sample statistics awaits further research.

In summary, the choice of interval size is nontrivial. It can determine, in fundamental ways, the amount of curve distortion encountered as a result of random error or information loss. An optimum interval size that minimizes the influence of these effects theoretically exits. In practice, however, it is difficult to determine, since the parent distribution is unknown. Use of the Sturges equation to estimate the optimum interval size is recommended. It provides an estimate that is reasonably close to the theoretical minimum; especially when the largest observable velocity available in the literature is used to estimate the range of the species.

Smoothing Data Using Running Means

One of the common techniques used for smoothing the data during histogram analysis is the application of a succession of 3-point running means. Morhardt (1986) found that, in general, better fits are achieved using this technique than in fitting standard polynomials to the data. To investigate the power of this technique, we applied a 3-point running mean to our random sample of 200 velocities. All smoothing was applied to the original frequency histograms; these were normalized afterward to produce the suitability curves shown in the figures. There are two basic variables to consider when evaluating the effectiveness of the running mean technique. One is the interval size of the original histogram (before smoothing); the second is the number of times (passes) a running mean is calculated during the smoothing process. Figure 5 shows the result of applying a sequence of passes to the velocity frequency histogram based on an interval size of 0.01 (the original resolution of the data). The effect of the smoothing process is to eliminate (or combine) many of the peaks and smooth out the valleys. Note that after ten passes the curve is no longer ragged, yet its shape is complex and polymodal. The effect of applying the running mean smoothing technique at this level of data resolution (0.01 interval size) is to accentuate the "noise" created in the histogram as a result of the random sampling process. This result is one that should be strongly avoided and shows the importance (and nontrivial nature) of choosing a proper interval size prior to applying any smoothing technique.

Figure 6 shows the residual sum of squares obtained for each pass of the 3-point running mean technique. This shows that the amount of error drops dramatically during the first few passes (less than five). Additional passes beyond five have little or no effect on the residual error. Beyond nine passes, repeated application of the technique is analogous to "scat polishing." The rapid drop in error during the first few passes is also very misleading; comparing the lowest error in Figure 6 with the lowest error obtained by varying bin size (Figure 3) shows that much more can be gained via proper selection of interval size than application of the 3-point running mean. The minimum error associated with changing interval sizes is $R = 0.005$, whereas, minimum error for running means is $R > 5.0$ (i.e., far above the curve shown in Figure 3).

Most investigators will group their data at some level of resolution before applying the smoothing technique. The above results, therefore, may be of interest to show what happens in extreme cases, but in practice this is avoided through common-sense data analysis. A more relevant question is what would happen at some interval significantly less than the "optimum," but

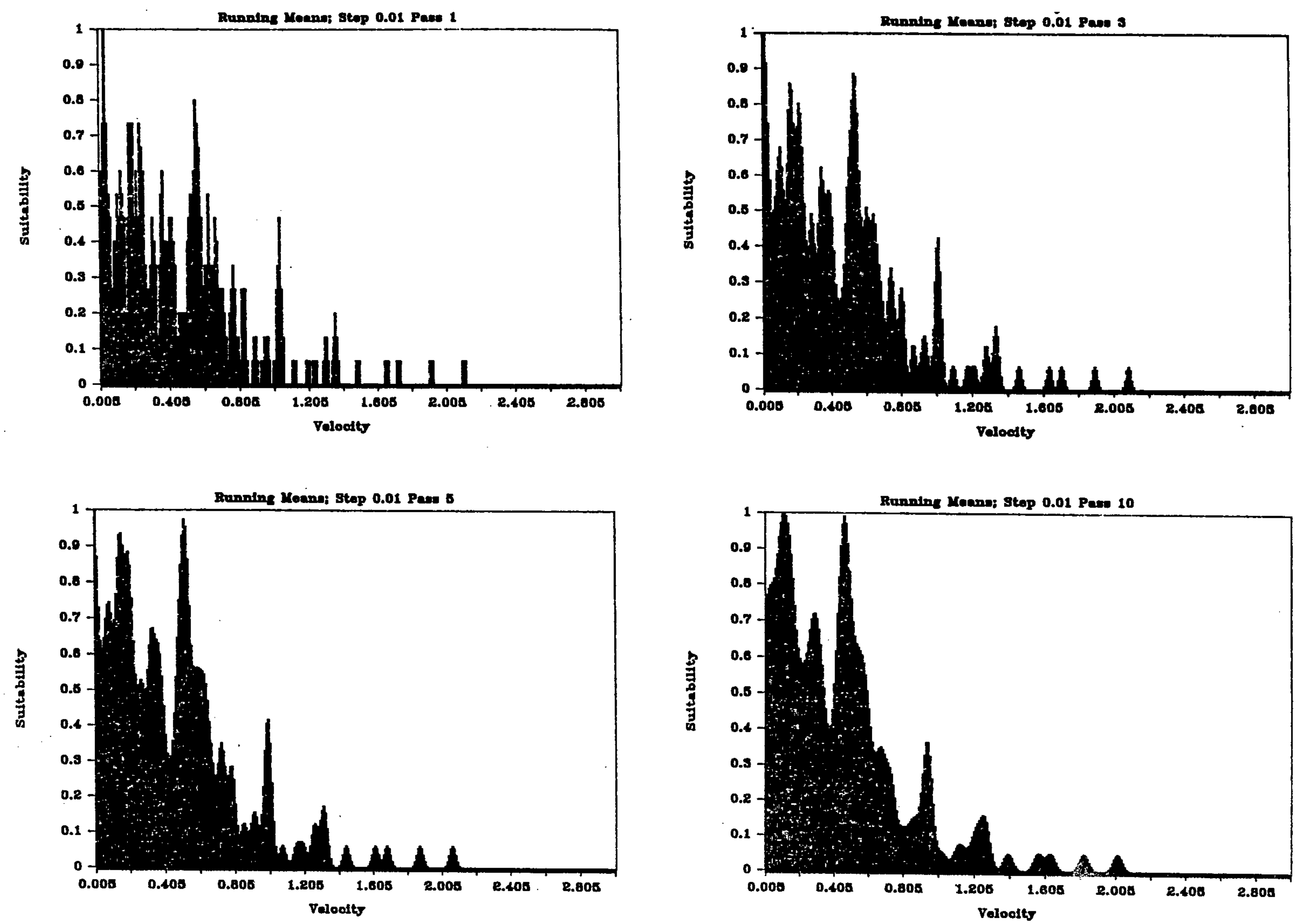


Figure 5. The effect of smoothing through the use of 3-point running means on a normalized frequency histogram (suitability function) with an interval size of 0.01 fps.

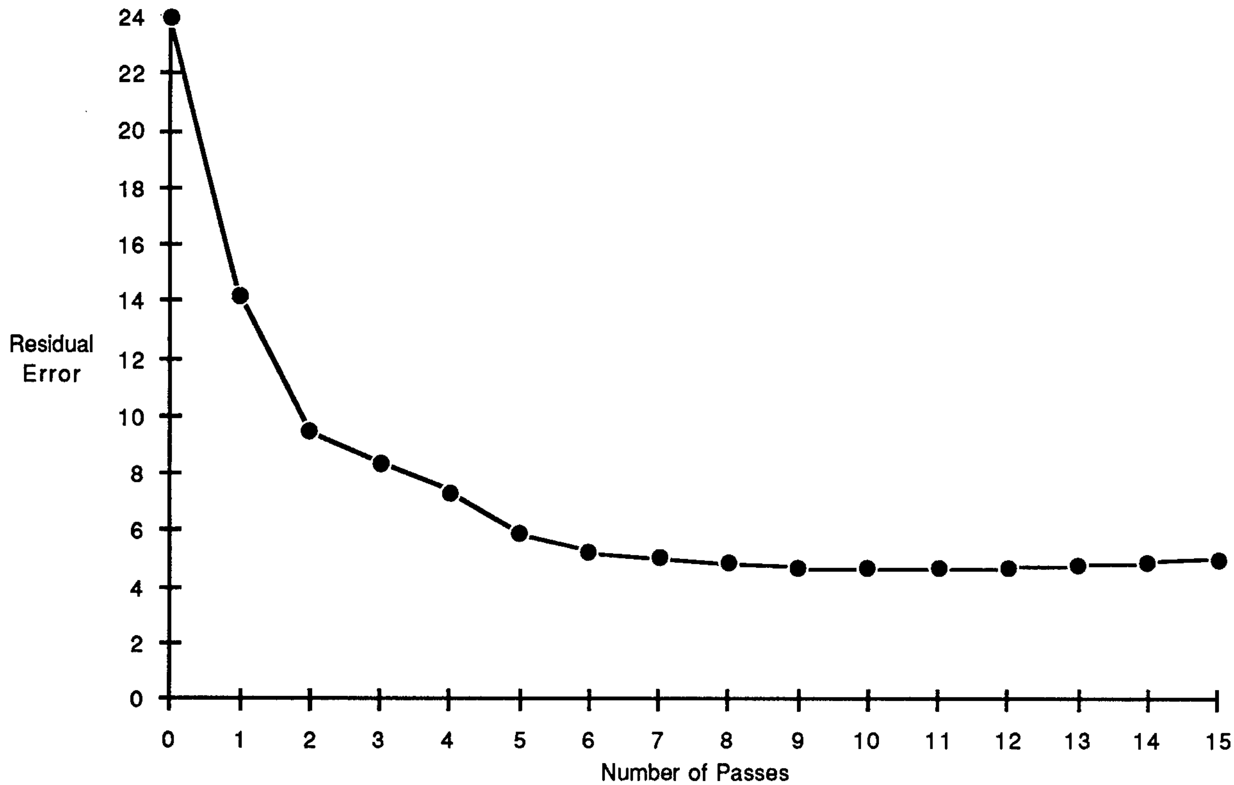
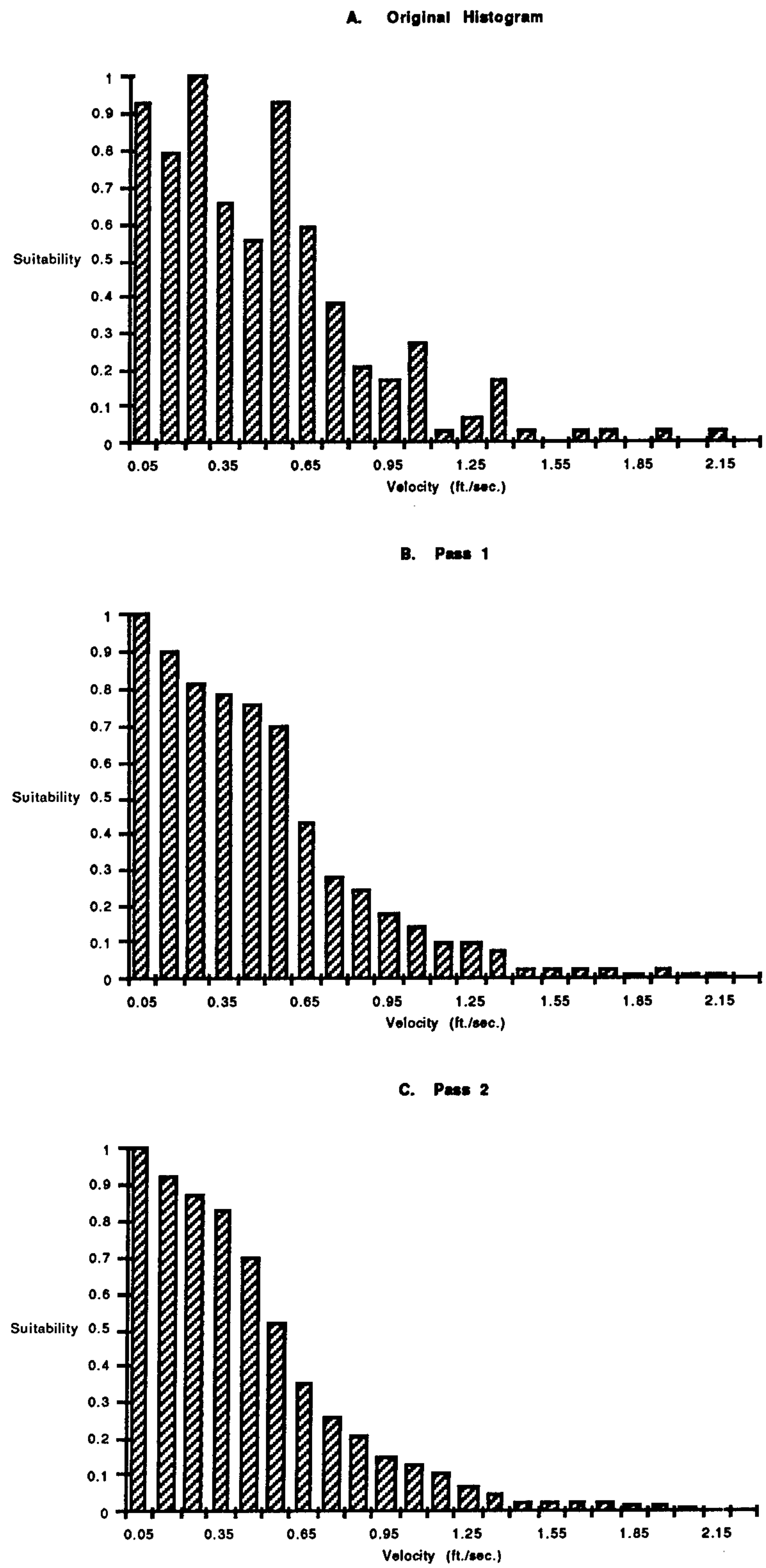


Figure 6. The total residual sum of squares vs. the number of passes applied with the 3-point running mean smoothing technique. An interval size of 0.01 was used to construct the frequency histograms; this was normalized to create a suitability function.

reasonable from a common-sense perspective. Let us consider the frequency histograms and suitability curves obtained with an interval size of 0.1. Figure 7 shows the suitability histograms obtained by successive passes. The original data are smoothed significantly in the first few passes of the running-mean technique. The original histogram (pass 0) has many minor peaks and valleys; after the first pass, a unimodal curve, declining as velocity increases, is obtained. Further application of the technique accentuates the decline, making it appear almost exponential in form. This is very similar to what occurred when large interval sizes began to distort the distribution (see the previous section).

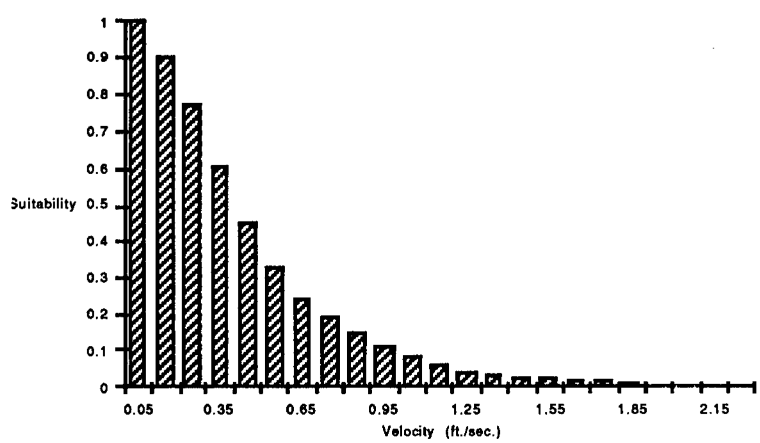
Figure 8 shows how residuals changed during each pass of the running mean technique. As pointed out earlier, the amount of error associated with the nonsmoothed histogram is much lower with this interval size (compare Figures 6 and 8). More importantly, a single pass has significant effects on the reduction of error. A second pass slightly increases the error. After three passes you are back to the same error level as the original curve, and with more than three passes the error increases significantly. As in Figure 7, there is a point where further smoothing results in little further change (after eight passes).



(Continued)

Figure 7. The effect of smoothing through the use of 3-point running means on a normalized frequency histogram (suitability function) with an interval size of 0.1 fps.

D. Pass 4



E. Pass 8

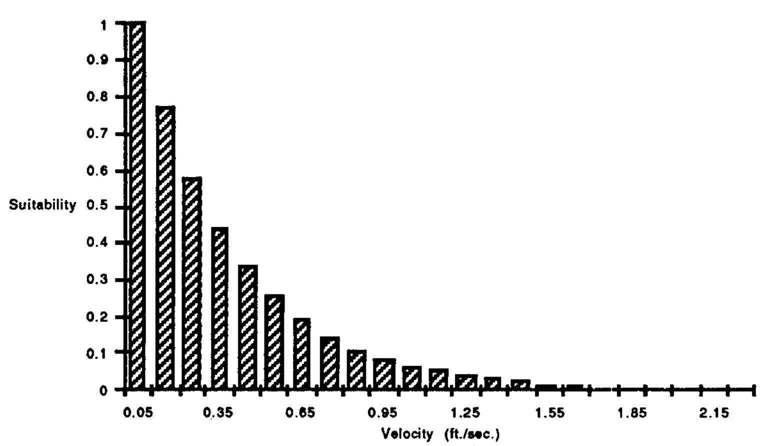


Figure 7. (Concluded)

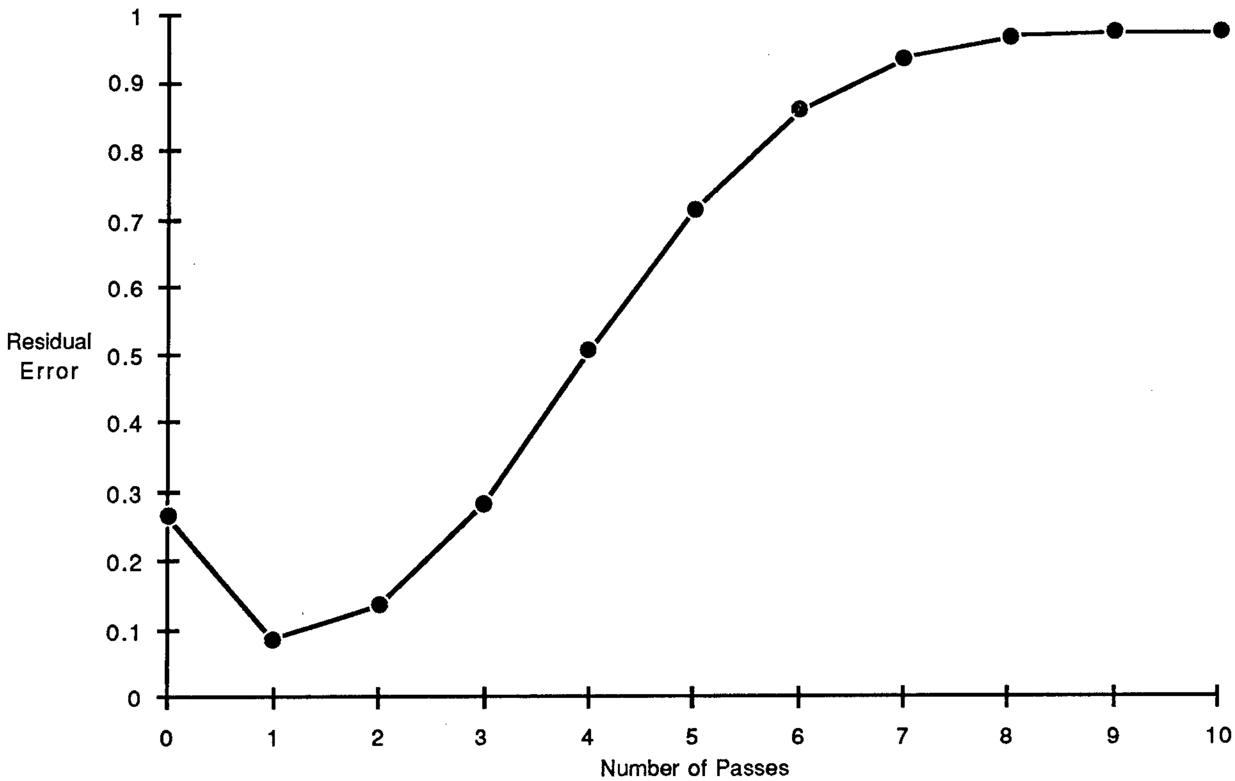


Figure 8. The total residual sum of squares vs. the number of passes applied with the 3-point running mean smoothing technique. An interval size of 0.1 was used to construct the frequency histograms; this was normalized to create a suitability function.

Comparing the residual error after one pass with the minimum error obtained by setting bin sizes indicates that choice of an optimum interval size is still more effective in controlling error than a running mean smoothing technique (compare Figures 3 and 8). Since, in practice, the optimum interval size is unknown (and estimates such as the Sturges equation may be inaccurate), these results indicate that improvements in fit can be achieved by applying a few passes of a 3-point running mean smoothing technique. Common sense is probably the best guide here; if the histogram contains many irregularities, even after estimating an "optimal" interval size (e.g., using the Sturges equation), it might be appropriate to attempt further smoothing. Proceed with caution, however, because this may undo any gains obtained through choice of interval size. We suggest that not more that two passes be applied to the data. This guideline is based on inspection of Figures 6 and 8. Note that if the estimate of interval size is far below the optimal (as in Figure 6), significant reductions in error occur within two passes. If the estimate of bin size is closer to the optimal (as in Figure 8), one pass helps significantly, while two passes do not undo the gains already obtained (i.e., error is not increased significantly over one pass).

To illustrate this point, we applied a 3-point running mean technique to the frequency histogram constructed with the interval size predicted by the

Sturges equation. Recall that when we used our sample data, the Sturges equation estimated the optimum interval size at 0.25. Figure 9 shows the histogram resulting from this choice of interval size. Without any smoothing there is a secondary peak at V = 0.625 in these data; if we apply one pass of the 3-point running average the secondary peak is removed, and a histogram close to the parent distribution is obtained. Figure 10 shows the residuals obtained through repeated application of the smoothing technique to the 0.25-bin-size histogram. As predicted, the application of one pass of the running-mean smoothing process reduced the error; additional passes caused the error to increase rapidly. After one pass, however, it is visually obvious that further smoothing offers no definite advantage. The one pass histogram displays a smooth, acceptable form, and common sense would indicate that no further treatment of the data is necessary (or valid). This example demonstrates the balance between selecting appropriate bin sizes and applying additional smoothing techniques to reduce the influence of random noise caused by sampling from a distribution.

As a final point, we analyzed what happens when the running mean technique is applied to a histogram constructed with the optimal bin size (0.3). Figure 11 shows the residuals obtained from this process; any additional smoothing causes the error to increase. If optimal bin size could be determined, further smoothing would be unnecessary. Compare the error obtained with proper selection of interval size (R = 0.005) with that of the Sturges method with one pass of the 3-point running mean technique (R = 0.039).

In theory, proper selection of interval size controls error more effectively than smoothing with running means. In practice, the optimal bin size is unknown and must be estimated from the data. The Sturges (1926) equation gives a reasonable estimate of the optimal bin size, especially if the range represents the known tolerance limits of the species. After choice of an interval size, some additional smoothing may be necessary, using a 3-point running mean technique. If additional smoothing is attempted, however, it should be applied conservatively and cautiously (i.e., under most circumstances no more than two passes).

Nonparametric Tolerance Limits

The use of nonparametric tolerance limits was first advocated by Gosse (1982). Bovee (1986) further advocated this technique, on the grounds that it is easily applied, is not influenced by irregularities in the data caused by random sampling, and does not involve the selection of any particular distribution or curve shape.

We applied the nonparametric tolerance limits to the ordered sample as described in Bovee (1986). This technique involves placing an umbrella over the observed frequency histogram. Tables are used to determine which rank corresponds to an area of 50%, 75%, 90%, 95%, and 99% of the population for a given significance level. The observations, velocity in our case, are ranked in increasing magnitude.

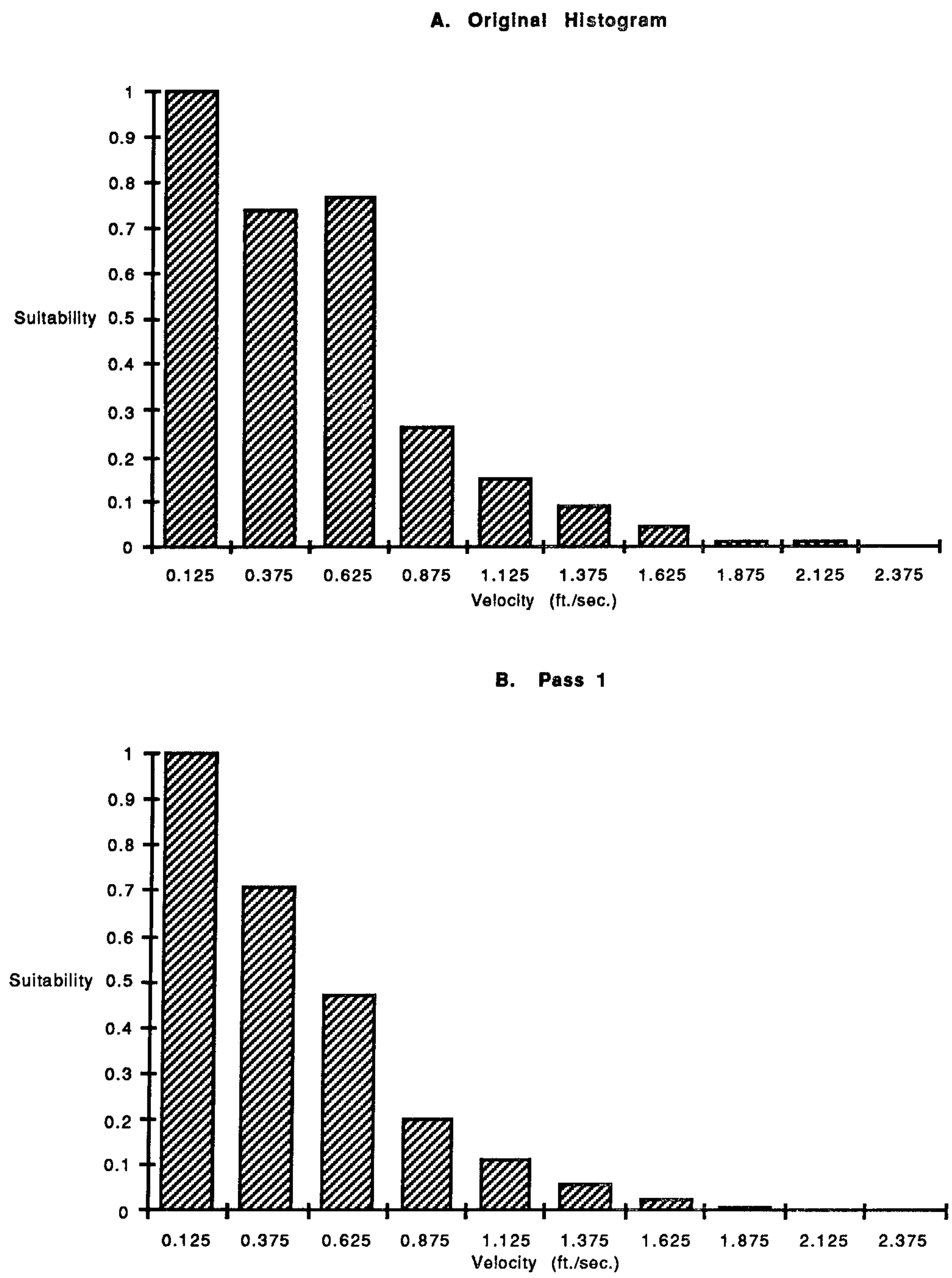


Figure 9. The effect of smoothing through the use of 3-point running means on a normalized frequency histogram (suitability function) with an interval size of 0.25 fps (the estimated optimal bin size based on the Sturges equation).

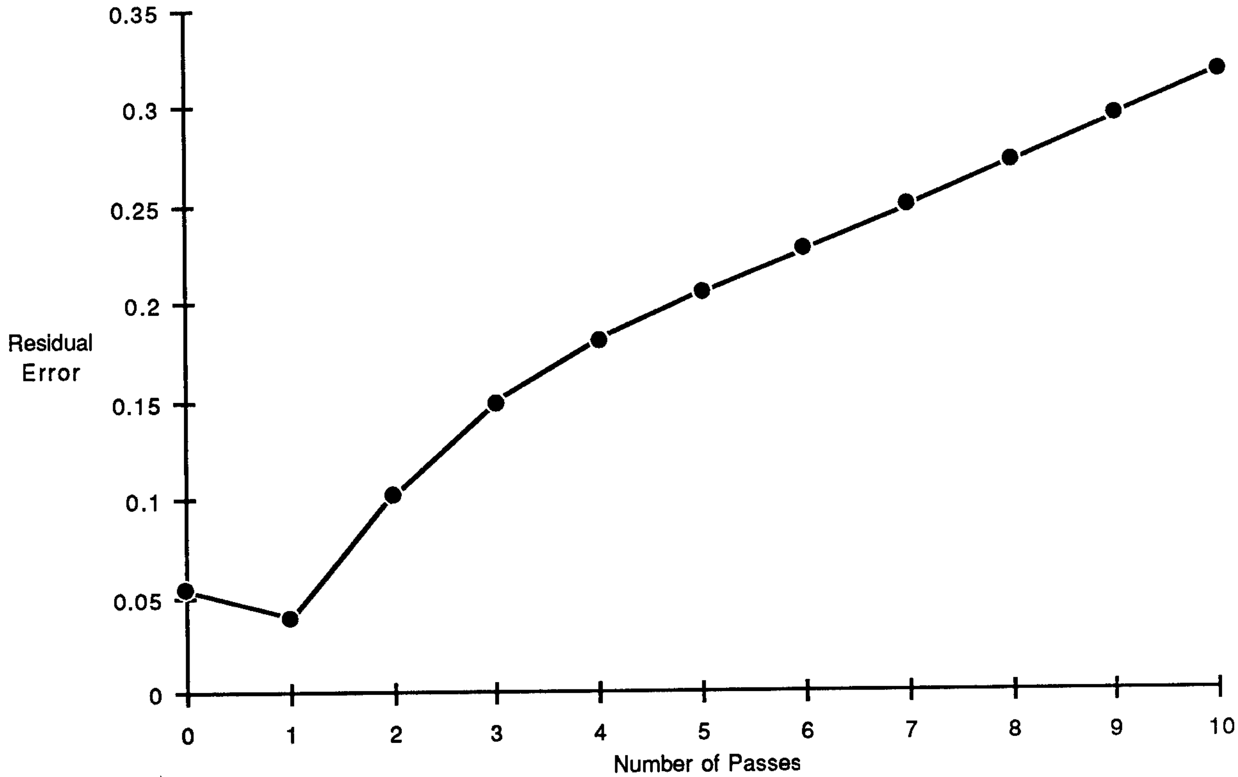


Figure 10. The total residual sum of squares vs. the number of passes applied with the 3-point running mean smoothing technique. An interval size of 0.25 was used to construct the frequency histograms; this was normalized to create a suitability function.

For example, at a confidence level of 0.50 and a population size (n) of 200, the rank that would encompass 50% of the observations would be 100 (from Table 8, Bovee 1986). The velocity associated with this rank is 0.41 fps. The suitability assigned to this proportion can be calculated from (Bovee 1986):

$$NSI = 2(1 - P) \tag{4}$$

where NSI = the normalized suitability index (from Gosse 1982)

P = the proportion of the population under the curve

Applying this definition to the above example, the velocity of 0.41 (associated with the 50% proportion) would have an NSI = 1.0. In this way a suitability envelope over the frequency histogram can be constructed with a given confidence level. In the above example we used the 0.50 confidence level; that is, we are only 50% confident that the umbrella constructed over the observed frequency histogram encompasses the real curve.

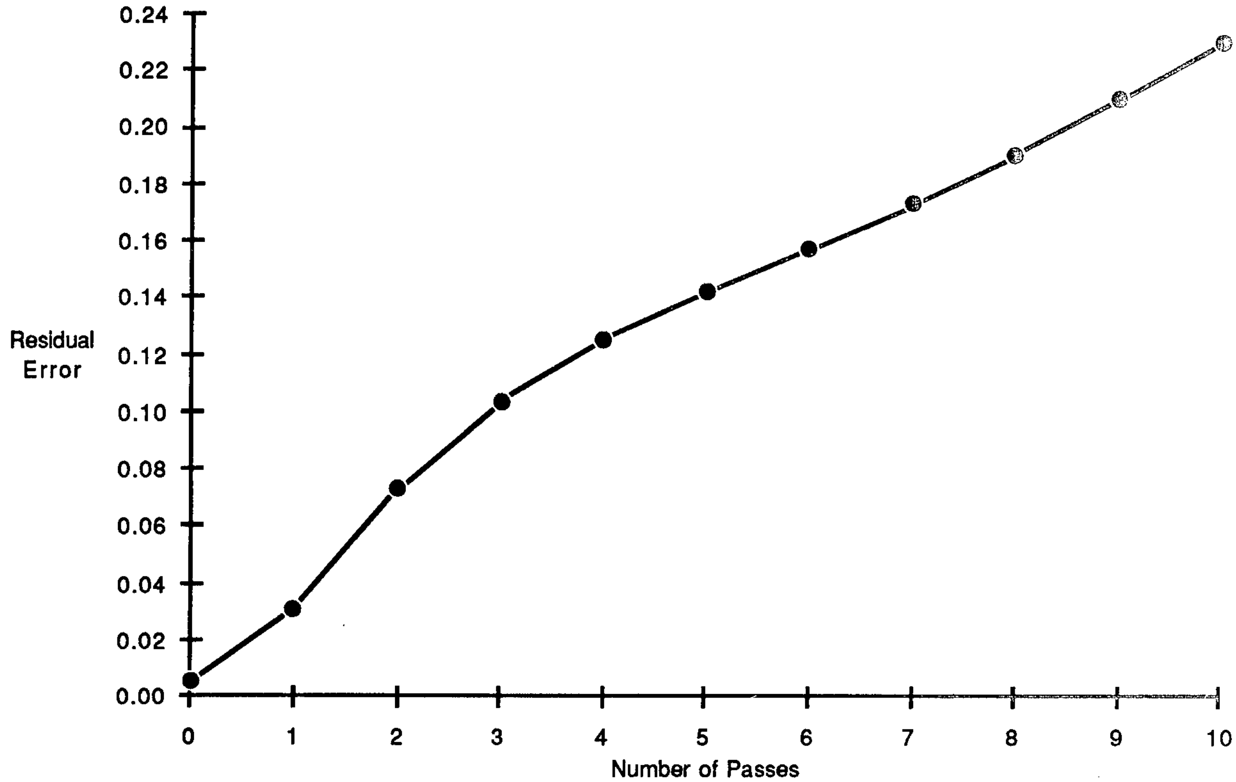


Figure 11. The total residual sum of squares vs. the number of passes applied with the 3-point running mean smoothing technique. An interval size of 0.30 was used to construct the frequency histograms; this was normalized to create a suitability function.

Figure 12 shows the suitability curves obtained for our velocity data by the nonparametric tolerance limits technique, using confidence intervals of 0.50, 0.75, 0.90, 0.95, and 0.99. Since the parent distribution is actually known, we can compare the different curves with this distribution to assess accuracy of prediction. Note, first of all, that the general shape of the curve is well preserved by the application of this technique. In other words, the influence of random error in introducing extraneous peaks or valleys in the SI curve is eliminated. This is the principal advantage identified by Bovee (1986) in his assessment of this technique, and his conclusion is supported by these data. Also, we see that as larger confidence intervals are used the envelope extends further out from the origin. Thus, as greater and greater confidence is obtained that the true curve is, in fact, within the umbrella of the chosen curve, accuracy is sacrificed. To illustrate this, the residual error between the chosen and known distribution was calculated. Figure 13 shows how residual error increases as the confidence intervals increase.

At a confidence level of 0.50, an error roughly equivalent to a one-pass 3-point moving average (with an estimated optimum interval from the Sturges equation) was obtained (Rnonpar = 0.048 vs. R3-point = 0.039). With a confidence interval of 0.90 the error for the nonparametric tolerance limit

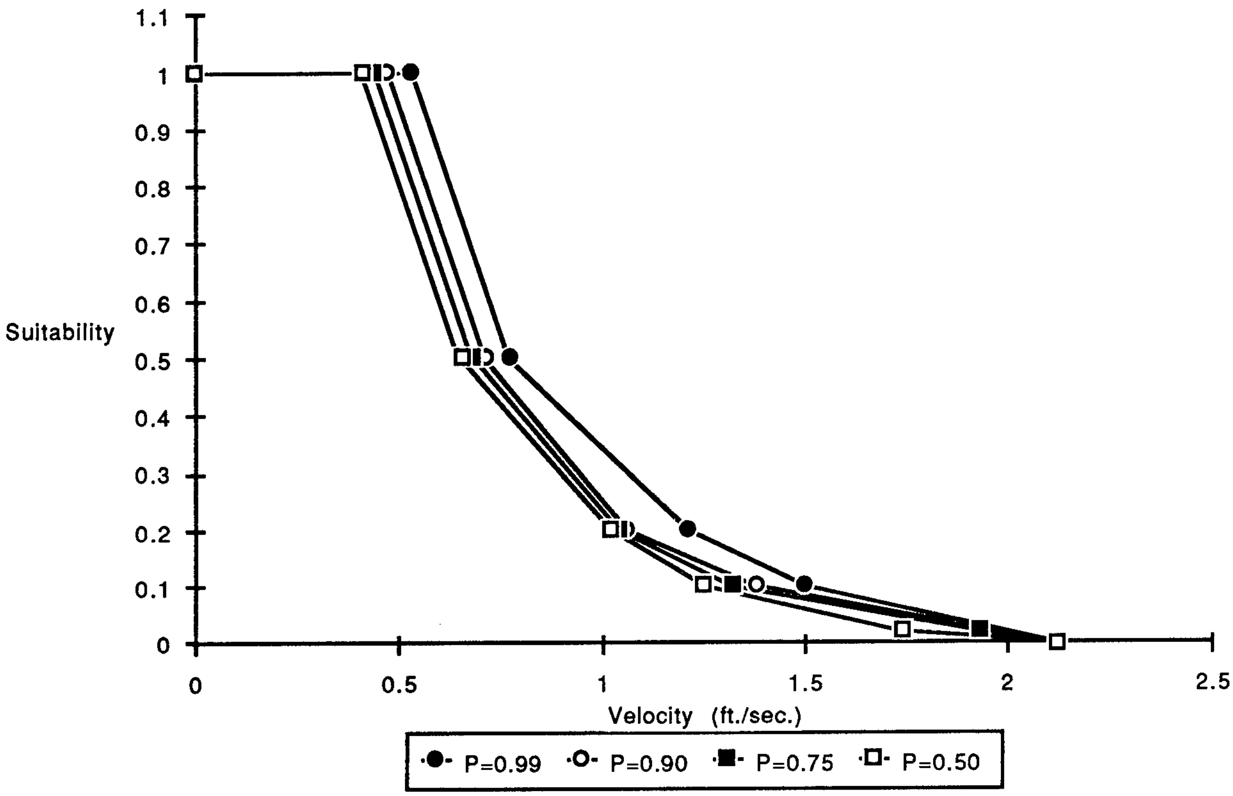


Figure 12. The suitability functions derived by use of the nonparametric tolerance limit technique for probability levels of 0.5, 0.75, 0.9, and 0.99.

was double that of the 3-point running mean (Rnonpar = 0.077 vs. R3-point = 0.039). The error did not become very large, however, until a confidence interval of 0.99 was used (R = 0.13). Note that in these data the process of accurately chosing the optimal interval size would produce even better results than any application of the nonparametric tolerance level technique (Roptimal = 0.005 vs. Rnonpar = 0.048).

In the world of uncertainty, however, it could be argued that the use of a 0.90 significance level nonparametric tolerance limit has great advantages. First, we can be relatively confident that the true curve is within the chosen curve. Second, the error obtained by chosing this curve over the other methods used in our analysis is not prohibitively great (i.e., even though the error was doubled it remained relatively small). In applications where very serious consequences could result from misidentifying the curve, a conservative approach such as this should be avoided. More accurate results may be obtained by proper choice of interval size combined with carefully applied smoothing.

Finally, it is possible to misapply the nonparametric tolerance limit technique. For example, if we had superimposed a two-tailed envelope on these data (Figure 14) a significant error would result. With the data set treated here, this seems an absurd possibility. Yet with other data sets (based on

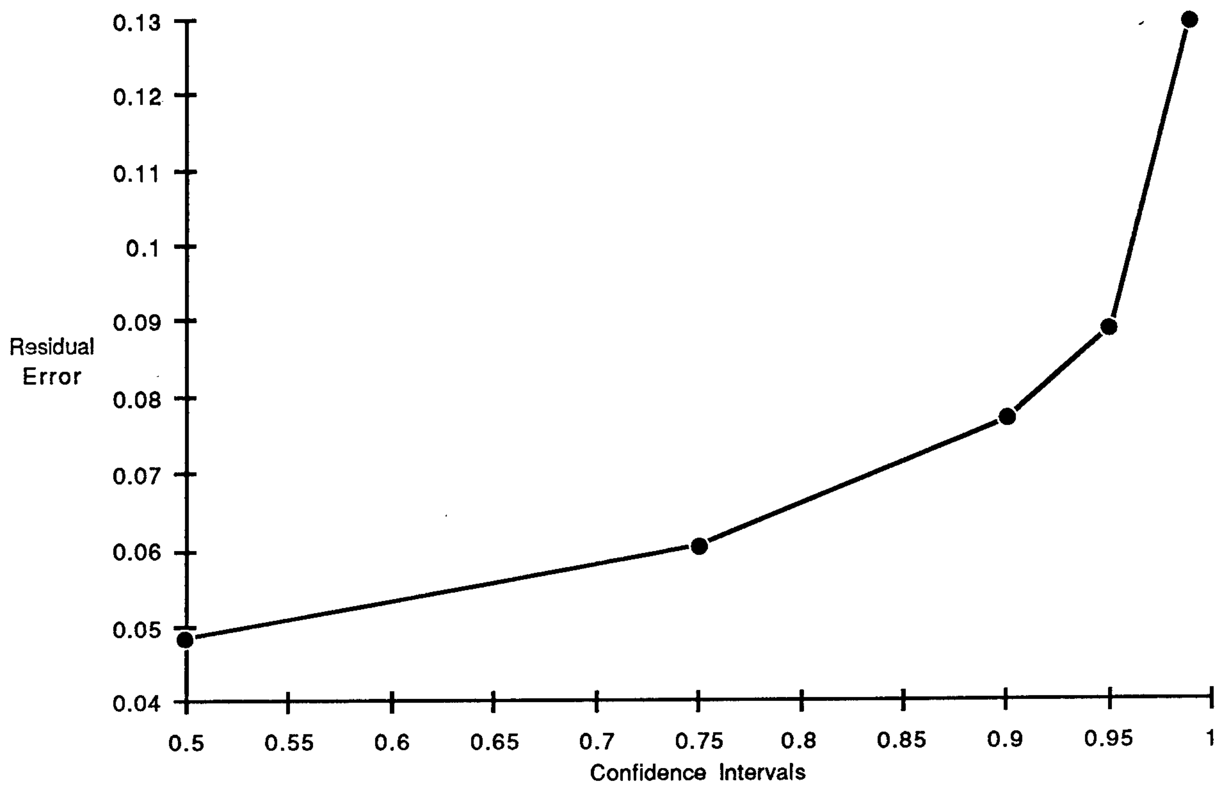


Figure 13. The total residual sum of squares vs. the confidence intervals used to construct the nonparametric tolerance limit suitability curves.

fewer observations) or with underlying distributions that are skewed or multimodal, this problem can become nontrivial. Thus, the claim that this method does not assume any particular distribution is, in a way, misleading. The researcher must know some of the fundamental features of the distribution (e.g., whether it is skewed one way or another) in order to apply the technique successfully. Consequently, we recommend that choice of interval size (using the Sturges equation or some other method) and carefully applied smoothing techniques be used in conjunction with the nonparametric tolerance limit approach to identify basic properties of the distribution.

SUMMARY

This paper attempts to determine the error associated with applying various smoothing techniques to suitability index curves based on frequency histograms. Our basic approach was to create a theoretical population suitability curve, sample randomly from this curve, apply commonly used smoothing techniques to the results, and evaluate the difference between the parent and sample distributions. Through the use of a residual sum of squares we were able to place the comparison process on a firm quantitative foundation. Various response curves were thus obtained as we changed curve smoothing techniques. Two techniques used in histogram analysis were investigated:

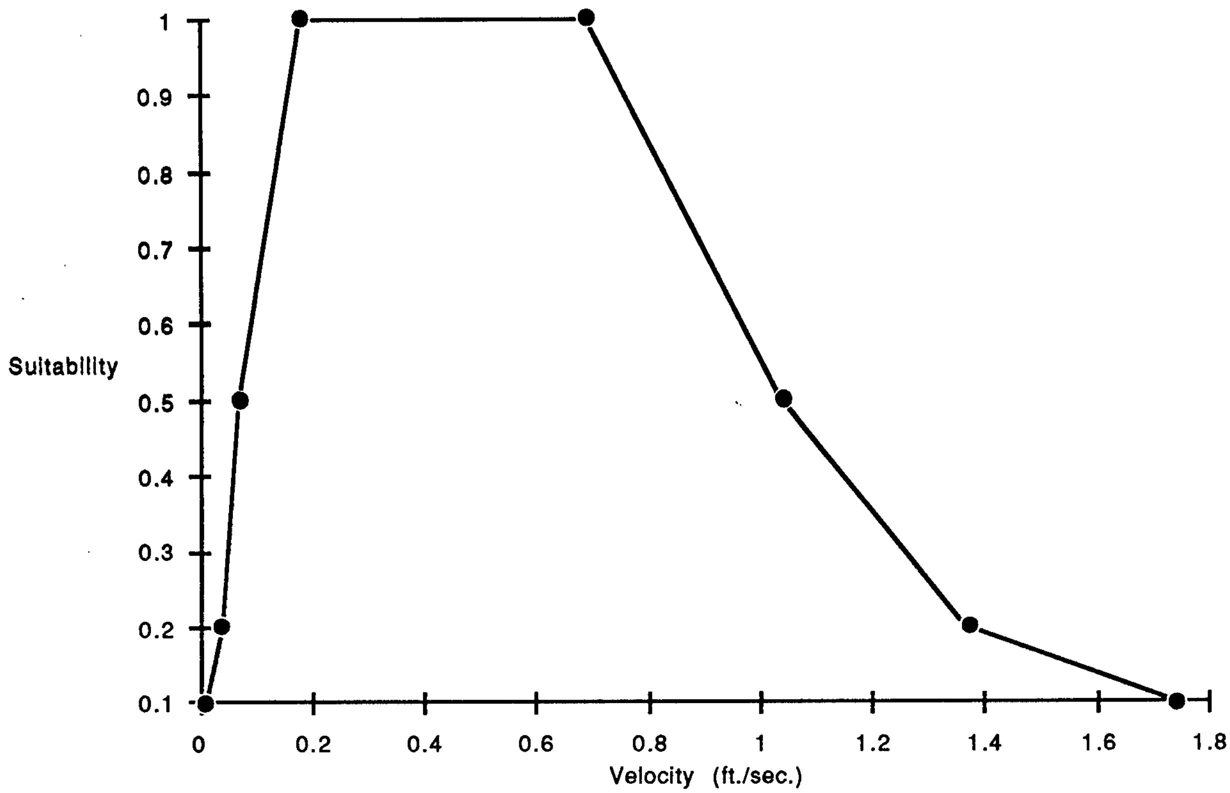


Figure 14. The suitability function derived by misapplication of the non-parametric tolerance limit technique. A symetrical rather than a skewed distribution was fit to the sample data. This resulted in a residual sum of squares of R = 2.057.

choice of interval size and the 3-point running mean smoothing procedure. The nonparametric tolerance limit approach also was investigated, due to the potential benefits ascribed to this technique.

The technique that produced the least error, of all investigated, was the rather simple procedure of choosing the optimal interval size for constructing the frequency histogram. In theory, this choice significantly reduces the error resulting from random sampling or curve distortion due to information loss. In practice, the choice of optimal interval size is difficult, since attributes of the parent population are unknown (such as the actual range). Use of the Sturges equation, as an estimate of the optimal interval size, proved to be valuable, since the error associated with this technique was small. Furthermore, use of all available data to estimate the range of a species/life stage tolerance for a given variable significantly improved the performance of the Sturges equation. Until other techniques of estimating the optimal interval size are investigated, we recommend use of the Sturges equation to estimate this parameter. Careful choice of a proper interval size should be the first step for any additional data analysis or curve smoothing.

Because the true optimal bin size is unknown, additional smoothing may be necessary. Application of the 3-point running mean technique proved to be effective (after proper choice of interval size) in reducing the error

associated with random "noise." Our analysis indicated that this approach should be applied cautiously and conservatively. Serious errors occurred, due to curve distortion, as several passes of the 3-point running mean were applied to these data. As a general rule, we recommend no more than two passes be used when smoothing curves with this technique.

The technique that controlled error the least was the nonparametric tolerance limit. When a significance level of 0.50 was used, the error was equivalent to using a one-pass 3-point running mean (after proper choice of interval size). This significance level is rarely used, however, due to the relative uncertainty of encompassing the real (unknown) distribution. At a more reasonable significance level of 0.9 the error, as compared with the running-mean technique, was doubled. This underscores the problem faced by the investigator in the world of uncertainty known as curve fitting. As one increases the area encompassed by the umbrella of the curve, and therefore decreases the probability that the real curve is outside this umbrella, one also increases the probability that an error in the true position of the curve is being made. If mistakes in the true position of the curve have serious consequences (e.g., endangered species), this technique may not be the best to use. Also, proper use of this method involves knowing something about the underlying form of the parent distribution (i.e., is it skewed, normally distributed, polymodal, etc.) Note that when the proper shape (skewed left) was used, it was successful at reducing the effect of random "noise" in the data. Thus, accuracy may in some cases be less important than specifying the general shape of the curve. It is in these situations that nonparametric tolerance limits may prove most beneficial.

Common sense goes a long way in identifying acceptable suitability of use curves. Appropriate choice of interval size for the frequency histogram is the beginning of a sound analysis (e.g., using the Sturges equation). In fact, theory suggests that the most accurate curve may result from just connecting the midpoints of histograms based on the optimal interval size. Additional smoothing may be necessary using the 3-point running mean technique; if so it should be applied carefully, with few passes, to minimize distortion of the curve. Under circumstances where accuracy of curve placement is not as important as identifying the general shape of a function, nonparametric tolerance limits may be the most efficient method to use.

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QUESTION AND ANSWER SESSION

Ed Cheslak

Nelson: Are you saying that the Sturges equation can be used if you don't know what the distribution is? Let's say you've got a set of data and you have no idea what the apparent distribution is.

Cheslak: Yes. I believe that it can be used. I've experimented with that; if R was unknown, then what would happen to the interval size? If the apparent distribution is unknown, there are two possible ways of estimating the appropriate interval size. One is to say, "what velocity do I reasonably know as being the maximum velocity at which there will be zero individuals?" That velocity is then assigned as the range. The other way is to take a look at the maximum number in your data and assign that as the range. I don't believe that there's going to be an awful lot of error caused by that. You'll still be in the region of that minimum interval size.

Smith: How would you handle the depth on that Sturges formula?

Cheslak: The same way. You know what the range of depth would be. Is it 10 ft, is it 12 ft, 0-12 ft? I would put in the range.

Smith: Essentially it's maximum depth that you would put in?

Cheslak: Maximum depth, right.

Question from the floor: Can the Sturges equation be used with any kind of a distribution?

Cheslak: I'm not sure. Unfortunately, that particular citation resides in a bibliography that I couldn't track down. I haven't taken a close look at Sturges, but it's encouraging that there is such a close approximation.

Voos: The same equation is in one of Yuptovich's books, but the factor that's in there is wrong. I experimented with it and I believe it's off by a factor of 10. If you look at your numbers, you'll see that the function is the same, but that one coefficient is off.

Cheslak: I'm willing to try many more simulations to see if we can't narrow down that range and find a better coefficient, but I had a feeling that it's a robust kind of parameter.

Cambell: What would happen if you were working with habitat availability and utilization? You're trying to get category III criteria, but your intervals were different for both sets of data?

Cheslak: I'm glad you asked that question. We were talking about that very issue just recently. I'd use the Sturges equation, find out what the optimal

interval for availability was, construct the histogram, construct the curve by connecting the midpoints of the histographs together, and then do the same thing for the utilization data. I would construct both functions, then divide one into the other. I think that's actually a better way to do it, because you can deal with data sets in availability and utilization that are different sizes, and we can get around the problem we were discussing yesterday (irregularities of preference histograms--eds.). What happens when I'm trying to estimate availability from an IFIM analysis is that I may have thousands of points out there. I say use them all for both data sets. Why use only 200 of them because that's all the utilization data I have? Use all of it. Use a different interval size when you construct your histograms, and then use the curves when you do your division, not the histogram data.

Lifton: I have a couple of questions on how you calculate your residuals. When you calculated your residuals, say comparing 0.1 foot per second interval with the original curve, did you go on a 0.1 foot per second basis to add up the residuals of parent distribution?

Cheslak: No. I connect the midpoint with the point that would be predicted by the curve. It would be similar to a linear analysis where I wanted to calculate the residual between my regression curves and the actual points.

Lifton: So your total residuals are also going to be a function of the number of intervals that you've used. Wouldn't it be more appropriate to look at the mean squared error rather than the total sum of square errors?

Cheslak: Yes and no. I did look at the mean squared errors and I have some curves to show you the differences, if you're interested. When I used the mean residuals, the shape of the curve is essentially unchanged. But, the amount of climb when you get to low interval size is smaller. The reason that I would argue not to use mean residuals is that I'm mainly interested in how close those histograms get to the actual curve. I'm not interested in how much error I get per unit observation. That doesn't really tell me as much.

Lifton: Then it may be more appropriate to the PHABSIM simulations?

Cheslak: No, because what I do is look at how close the fit of the histogram is to the actual curve and minimize the total sum of squares. Then I smooth or fit the function to those histograms. By doing that, I minimize the total error. Let me try to explain that. When I gave you these values, I constructed a histogram, took the midpoint, and connected them with lines. Then I went back and compared it on a 0.01 basis. In other words, I kept sample size the same and I compared them and generated the sum of R squared. When I did that, I still came up with a very low sum of R squared. So, the process would be to identify appropriate intervals, use midpoints to approximate the curves as close as possible, and fit those with straight lines. That fit should be very close to your initial or original population. For that reason, I think it's appropriate to use the actual residual and then minimize that way instead of using the mean residual.

Locke: I have a comment and a question regarding the utilization and the availability iterations. When I was doing this, I set my intervals for my utilization because I believed that I wanted my fit to curves to be continuous.

I don't believe the fish is going to use velocities at 1 foot per second, not use velocities at a half foot per second, and then use them again at a quarter foot per second. That is an artifact of the sampling, or something. I believe there are so-called setback curves. With the availability intervals set exactly to utilization intervals, then I believe you'd get a step-like function, because you don't necessarily have available habitat for every interval. Then my question is, are you using Lotus 1-2-3 for all of this analysis?

Cheslak: I'll answer the second question first since it's the easiest. Yes. I used Lotus 1-2-3 for everything. If you want to know how, I'll show you how I do it. But in answer to your first question, I don't believe it's correct to use an arbitrary interval size based on what we think is meaningful to the fish. I don't believe it is appropriate to look at it that way. By determining the optimal interval size, you're trying to approximate the real curve. Once you get that approximation, you're going to join these midpoints by straight line increments. That implies that the fish are responding linearly across that interval. So if I have a suitability of one for the interval from zero to 0.3 feet per second, we must assume that they behave the same over the interval zero to 0.3. Then, from 0.3 out to 0.6 they would see that differently, and would start decreasing their utilization. I think we have to break the habit of saying these irregularities have biological meaning. I agree with you. This method does not inherently assume biological significance to irregularities in a distribution. This method attempts to approximate the real function by a histogram and I'll estimate the real functions with a series of straight lines.

Bovee: You've based your examples so far on continuous variables on integer scales. Will you run into the same problem I was talking about yesterday on cover and substrate, which are on ordinal or nominal scales?

Cheslak: Yes, you would. We might be able to get away with noncontinuous or discreet variables by looking at continuous partitions of that. It's a problem, and I don't really know how to respond. The best thing to do is to try to turn it into a continuous variable.

INVESTIGATIONS INTO THE USE OF BIVARIATE HABITAT SUITABILITY FUNCTIONS IN APPLICATION OF THE PHABSIM MODEL

by

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INTRODUCTION

For most instream flow studies in which the PHABSIM model (Bovee 1986) is used, independent univariate depth and velocity suitability functions are employed. The primary reason for this is the relative ease of constructing curves from field measurements, the simplest procedure consisting of fitting a curve by eye to a plot of the velocity or depth utilization data. More sophisticated methods involving mathematical curve-fitting or smoothing techniques are also used (Bovee 1986).

It has been argued by several authors that treating depth, velocity, and other physical parameters as equal and independent variables may be invalid and could lead to misinterpretation of model results (Orth and Maughan 1982; Mathur et al. 1985; Morhardt 1986). The problem often cited is the failure of independently derived univariate functions to incorporate interaction between variables, i.e., fish select habitat on the basis of complex interactions of several variables.

While few would argue that habitat selection by fish is most accurately described by the aggregation of independently derived suitability functions, relatively few attempts have been made to develop multivariate suitability index functions. Voos et al. (unpublished) suggested the use of exponential polynomial multivariate functions, and Thielke (1985) developed multivariate functions, using a logistic regression model, for trout in the State of Washington.

The reasons why few researchers apply multivariate analyses probably include the difficulty of displaying or visualizing habitat utilization over two or more variables, the large amount of data necessary to develop usable models, and, in some cases, computer memory limitations. The purpose of this presentation is to illustrate the degree to which analyses with bivariate models can be accomplished using readily available personal computer hardware

and software. In 1986, two-dimensional plotting programs, statistical packages with multiple regression capabilities, and two-dimensional smoothing techniques permit a considerable degree of simple analysis.

ANALYSIS

In this report we investigate two forms of bivariate analyses:

(1) exponential polynomial regression models using a least-squares solution technique, and

(2) two-dimensional smoothing algorithms.

A series of bivariate exponential polynomial models are evaluated and compared with the results of varying levels of curve smoothing, using adult brown trout (*Salmo trutta*) depth and velocity utilization data as a sample data set. In addition to the comparative evaluation of curve-fitting and smoothing techniques, differences within the curve-fitting approach are also investigated. These secondary evaluations are designed to isolate the differences in suitability response surfaces generated by bivariate and univariate models.

A total of 392 adult brown trout observations were collected from streams in a western Sierra Nevada river and its tributaries between 5,000 and 6,000 ft elevation. For these analyses the data were formatted into a 25 x 25 matrix of depth and velocity (Figure 1). Velocity data, grouped in 0.1 feet per second (fps) intervals, ranged from 0 to 2.4 fps; depth data, grouped in 0.2 ft intervals, ranged from 0 to 4.8 ft. The largest number of fish observations in any one cell of the matrix was 16. The general shape of the data indicates peak utilization at zero velocity, followed by a steep decline in utilization with increasing velocity, out to 2.4 fps. Depth utilization, on the other hand, is low at shallow depths, reaches a peak in the vicinity of 2 ft, and gradually tails off as depth approaches 5 ft.

THE EXPONENTIAL POLYNOMIAL MODEL

An exponential polynomial model of the general form

$$Z = \mathrm{EXP}\ (a + bV + cD + dDV + eV^2 + fD^2\ .\ .\ .) \qquad (1)$$

where Z = number of fish observed

V = mean column velocity

D = water column depth

$a, b, c\ .\ .\ .$ = equation coefficients

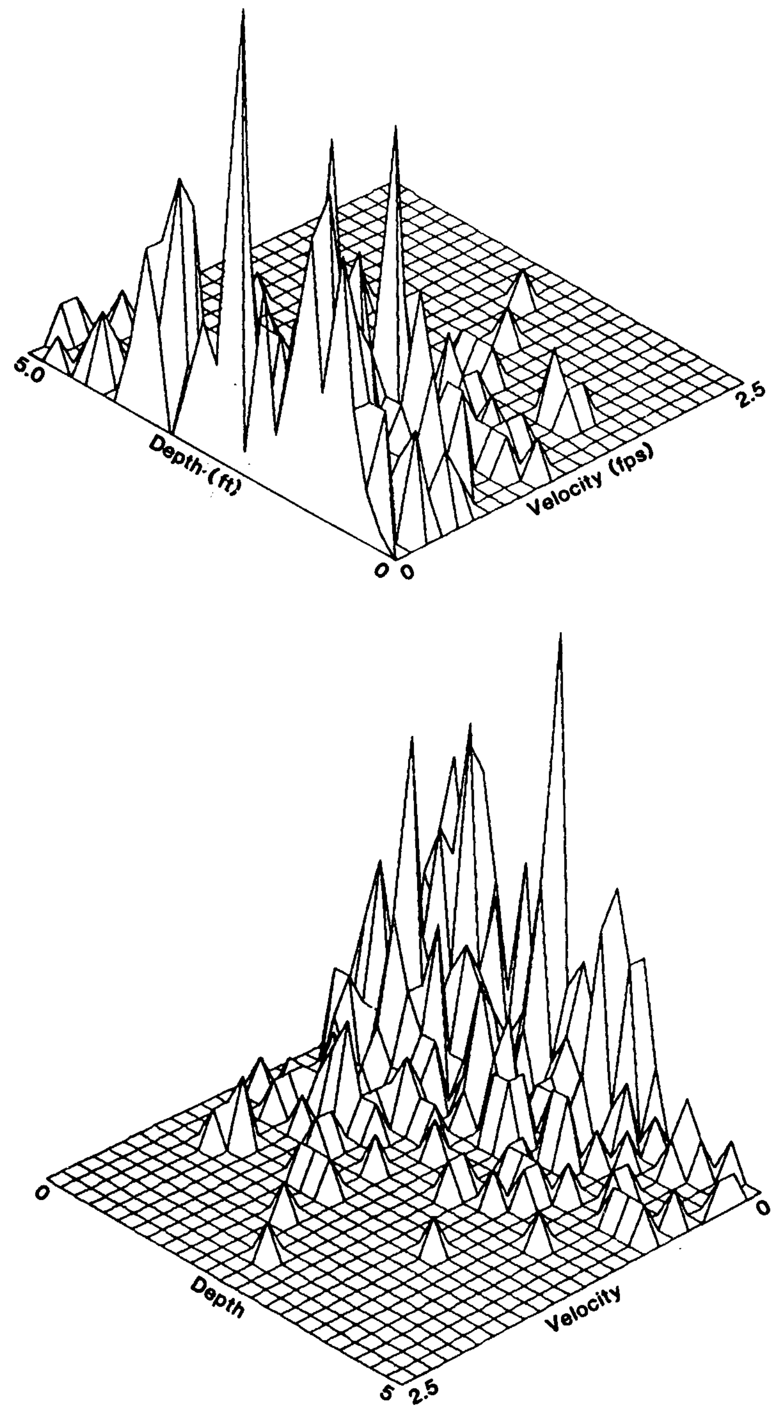

Figure 1. Frequency distribution of water depth and mean column velocity utilization by adult brown trout, seen in the origin aspect (top) and the maximum-value aspect (bottom).

was fitted to the data matrix using a least-squares regression technique.

The data were fitted to several forms of the exponential polynomial model, by varying the order of the depth and velocity terms and adding or removing the interaction term. The normalized response surfaces for each model tested are shown in Figure 2. A review of the response surface for each model leads to the following general observations:

1. A first-order model can only provide an exponential decay response in depth and velocity, permitting only a simplistic representation of the data.

2. A second-order model with no interactive term does not improve the response surface significantly above that of a first-order model. When an interactive term was added to the second-order model, it tended to drive the response down at the greater depths, the resulting response surface resembling that of the first-order function.

3. Third- and fourth-order models without interactive terms, while improving the fit somewhat, had a tendency toward unrealistic secondary peaks or "wings" at depth values between 3 and 5 ft. These trends were significantly dampened, however, by the introduction of the interactive term.

An important consideration related to the order of the fitted polynomial is the range of values over which the model is intended to be evaluated or extrapolated. The third-order model developed for these adult brown trout data (see Figure 2) illustrates this point. The response surface of this model indicates rising utilization at a depth of 5.0 ft, which would continue to rise beyond 5 ft in the absence of a fourth-order term. However, as long as the model is not evaluated at depths greater than 5 ft, it can be assumed to predict utilization accurately within the bounds of the original data base. Thus, when using higher-order polynomials, it is important to develop and review the response surface over the entire range of depth and velocity values that will be evaluated in an application of the HABTAT model.

Bovee (1986) recommended that exponential polynomial equations be restricted to the second order in the depth and velocity terms, on the grounds that a good fit with third- and fourth-order terms indicates bimodality in the response variable. The results of our investigations with the adult brown trout data do not support Bovee's recommendation. Our findings suggest that models of higher orders are not necessarily associated with sharply delineated bimodal distributions, but rather may be, within the appropriate data range, the best models.

From the several models investigated, a final best-fit model was selected, the one that produced the largest coefficient of determination with the fewest terms (Figure 3). This model contained depth terms expressed to the fifth order, velocity terms to the second-order, and a first order interaction term. The coefficient of determination for the model was 0.526. This model was used in the comparative analyses.

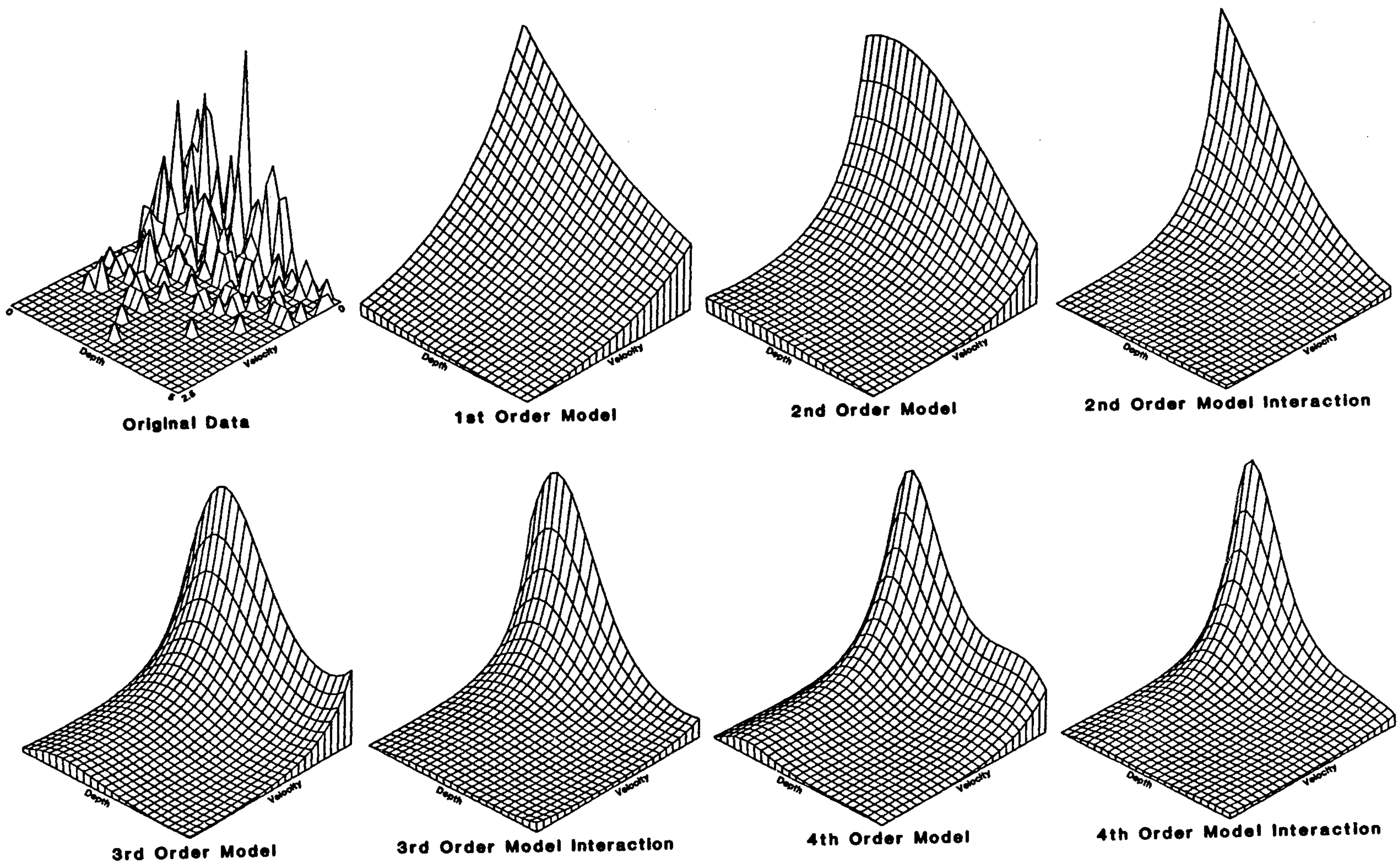

Figure 2. Response surface plots for several depth and velocity bivariate exponential polynomial model fits to adult brown trout utilization data.

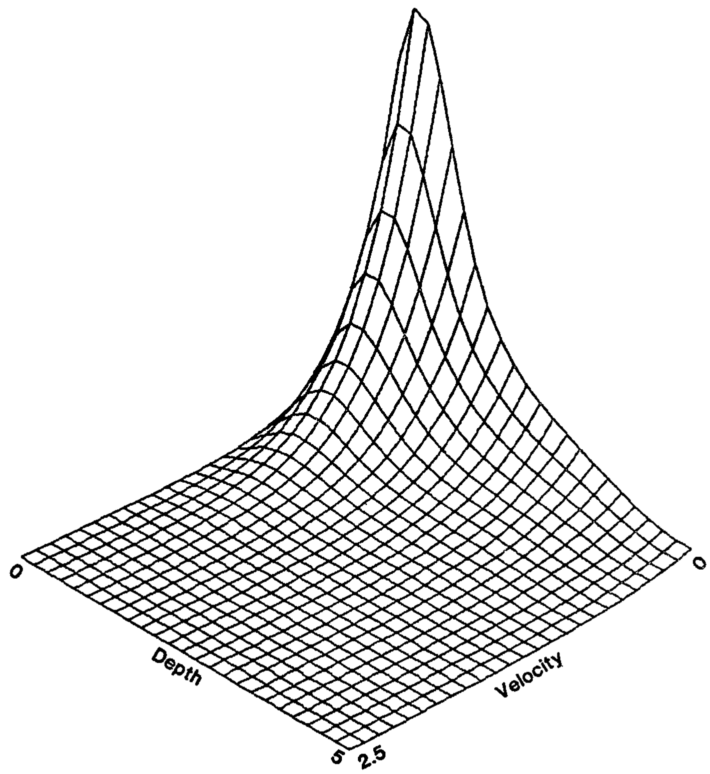

Figure 3. Best-fit bivariate exponential polynomial model for adult brown trout.

COMPARISONS TO UNIVARIATE MODELS

The adult brown trout data were grouped into independent depth and velocity data sets to permit comparison of the results of applying the bivariate exponential polynomial with the standard univariate model approach typically used in PHABSIM applications. This process can be visualized as simply summing the matrix data over depth in one case and over velocity in the other (Figures 4 and 5). The resulting single-variable data sets were fitted to univariate exponential polynomial models.

Figures 6 and 7 illustrate a series of curves fitted to the data with polynomials of different orders for each variable. A best-fit model for each variable was selected based on the same criteria applied to the bivariate model. The best-fit depth model was a 6th-order polynomial with a coefficient of determination of 0.537; the best-fit velocity model was a third-order polynomial with a coefficient of determination of 0.829. The two best-fit models were then evaluated at the 25 intervals of the range for each variable. Depth utilization, for example, was computed for 25 values between 0 and 4.8 ft. The 25 values predicted by each polynomial model were then converted to joint utilization values by applying each of the three aggregation techniques available in the HABTAT model:

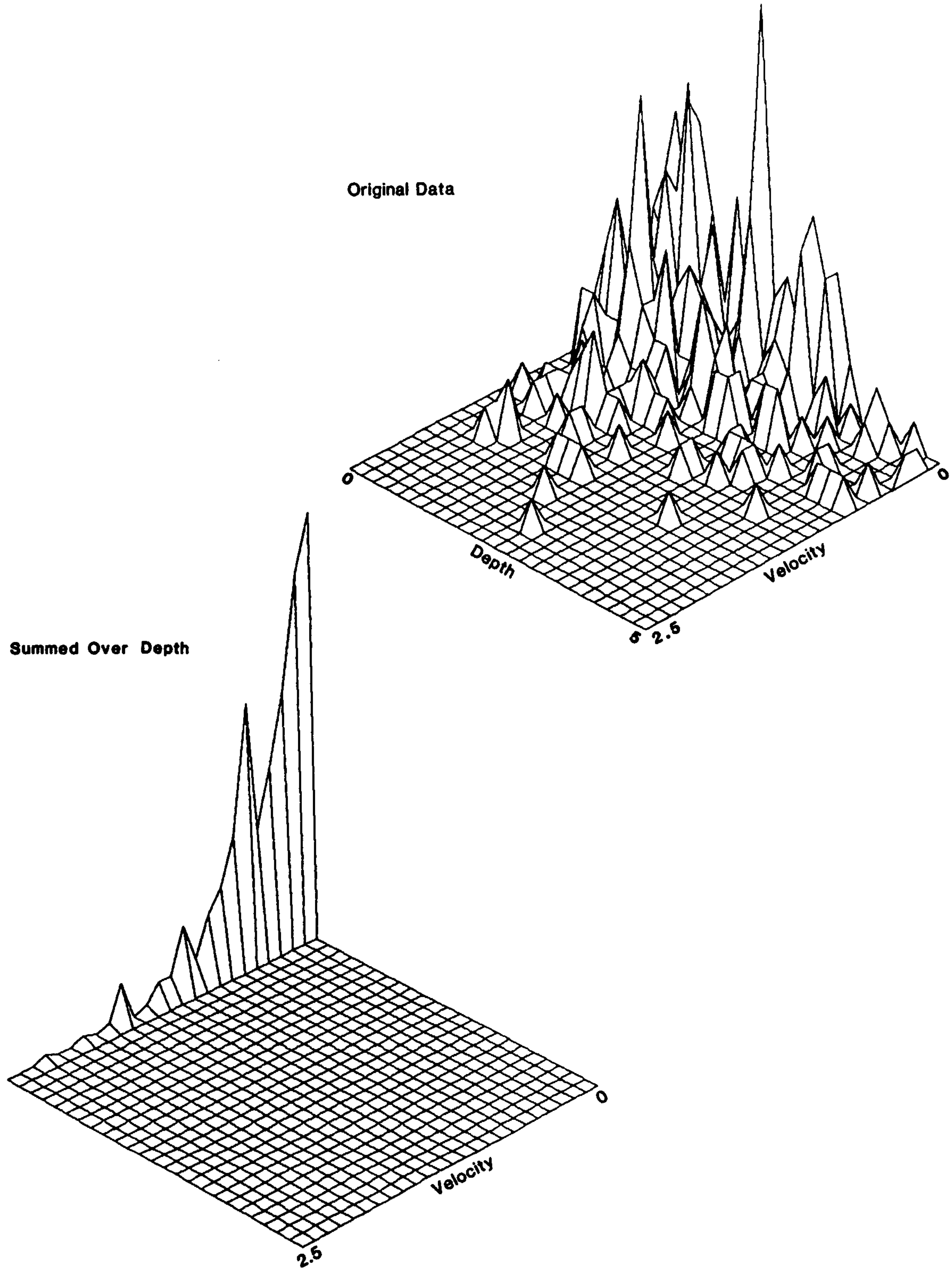

Figure 4. Creating a univariate velocity frequency distribution by summing matrix cells over depth.

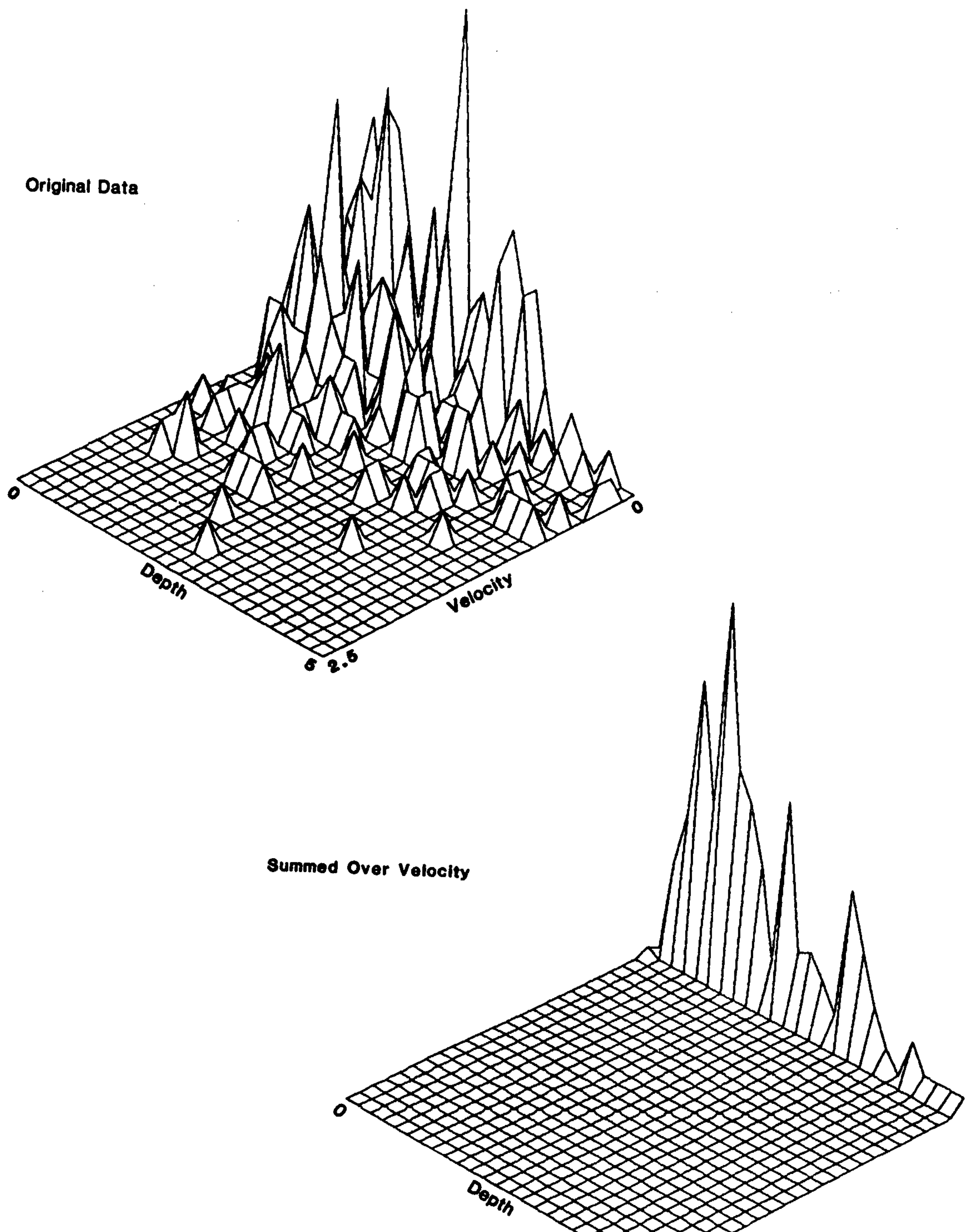

Figure 5. Creating a univariate depth frequency distribution by summing matrix cells over velocity.

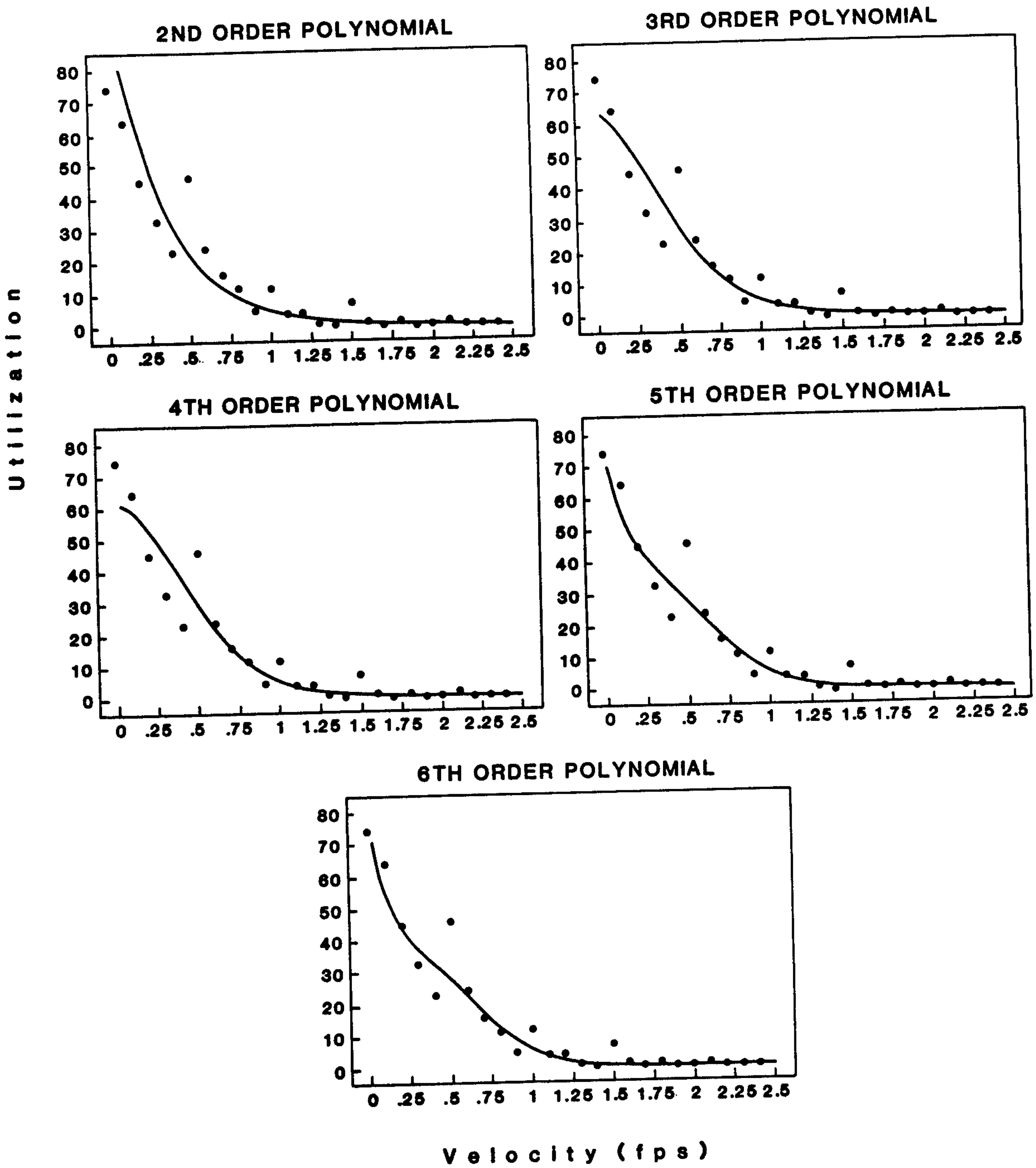

Figure 6. Curves of exponential polynomial functions fitted to adult brown trout velocity utilization data.

(1) multiplicative technique--(DxV),
(2) geometric mean--$(DxV)^{1/2}$, and
(3) minimum value--MIN (D, V).

The response surfaces associated with these aggregation techniques are presented in Figure 8, along with the response surface for the best-fit bivariate model.

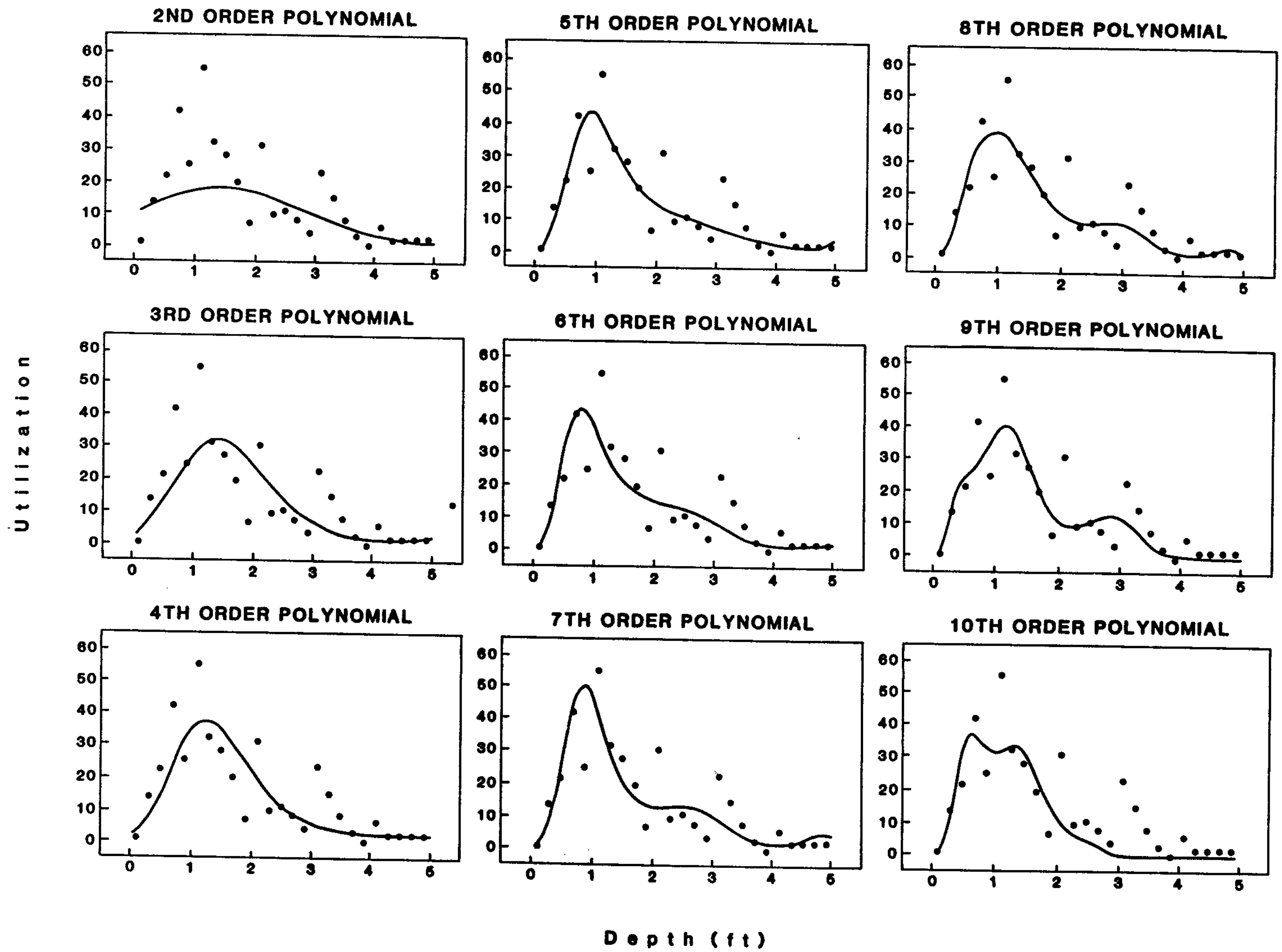

Figure 7. Curves of exponential polynomial functions fitted to adult brown trout depth utilization data.

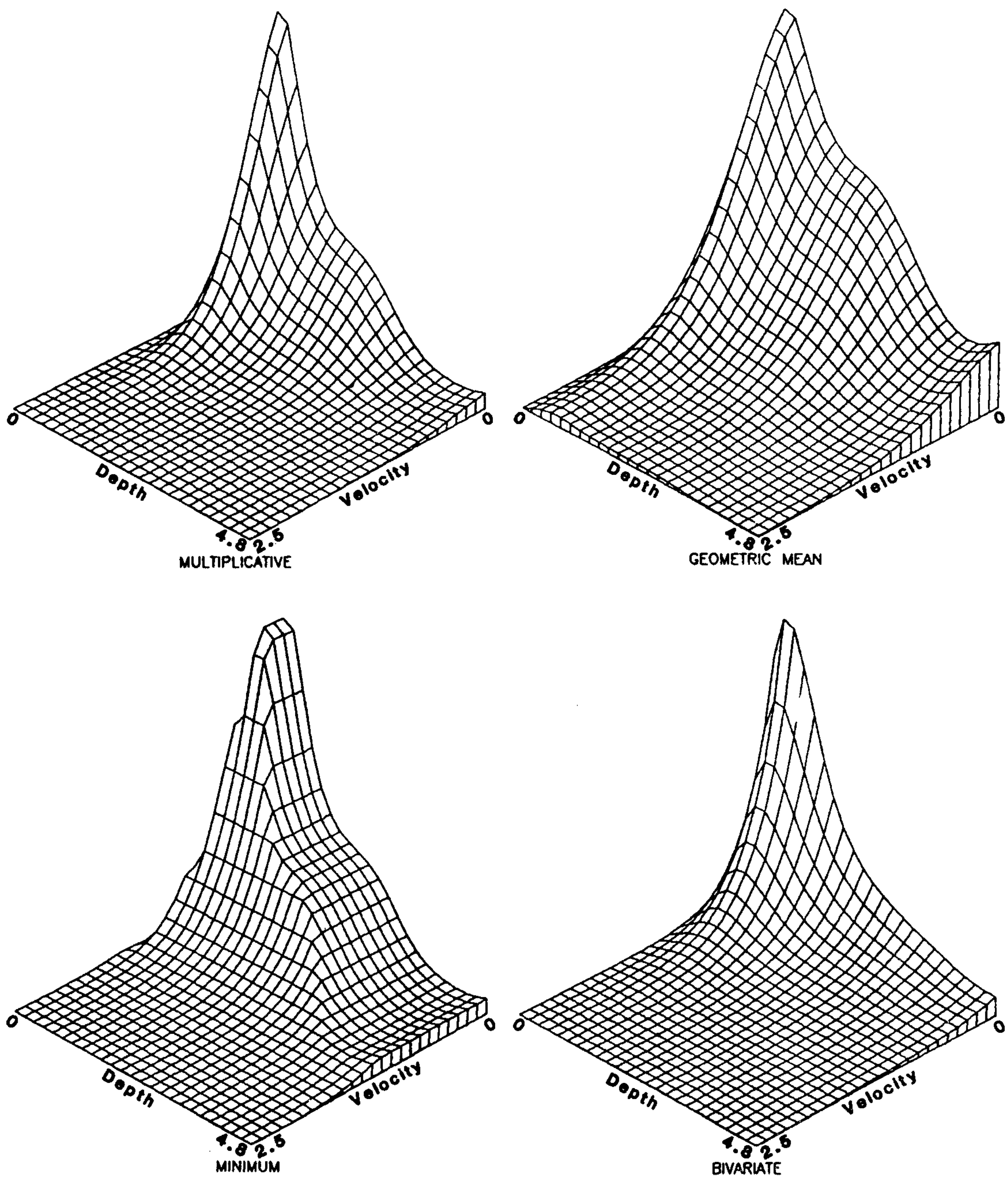

Figure 8. Habitat utilization response surface plots for three best-fit univariate models, using multiplicative, geometric mean, and minimum value aggregation techniques, and the bivariate model.

In comparing the response surfaces, it can be seen that the bivariate model and multiplicative univariate model are similar, and therefore would be expected to result in fairly similar weighted usable area vs. discharge rate curves when run through the HABTAT model. That the two response surfaces are similar indicates a weak interaction between depth and velocity; if there had been a significant interactive effect between the two variables, the bivariate model response surface would have deviated significantly from the symmetry of the multiplicative univariate response surface.

Although the response surfaces of the bivariate and multiplicative univariate models are similar, they differ in predicted utilization at zero depth. Contour plots of the two models (Figure 9) show that the bivariate model unrealistically predicts a level of 0.3 usability at zero depth, whereas the multiplicative univariate model predicts zero usability at zero depth.

Another observation from the comparison of response surfaces in Figure 9 is the larger volume under the geometric mean univariate response surface compared to the other univariate models and the bivariate model. This larger volume is due to the fact that the geometric mean of any two variables that range from 0.0 to 1.0 will always be greater than the product of the same variables (unless one of the variables is zero). The larger volume under the response surface of the geometric mean model will always lead to predictions of large amounts of weighted usable area, as demonstrated by Morhardt (1986).

The differences in volume beneath the response surface are further demonstrated by comparison of the sum of squared errors for the normalized response surface of each model:

Bivariate	Multiplicative	Geometric Mean	Minimum Value
5.57	6.21	20.25	13.44

The comparatively larger sum of squared errors for the geometric mean model is due mostly to the extension of higher levels of predicted utilization in the area of higher velocities and depths, illustrated by a plot of cell-specific squared-error terms (Figure 10). These results clearly demonstrate that invoking the geometric mean aggregation technique--and, to a lesser extent, the minimum value aggregation--leads to a bivariate response surface that is significantly different from the two-dimensional plot of original data.

These findings indicate that the hypothesized geometric mean aggregation technique does a poor job of describing how fish utilize combinations of depth and velocity, and should not be used in applications of the HABTAT model unless it can be clearly demonstrated that the resulting response surface closely matches that of the original data.

CURVE SMOOTHING TECHNIQUES

Two-dimensional curve smoothing was performed on the data matrix using the Inverse Distance Squared smoothing algorithm (IDS). The IDS algorithm smooths the data by replacing the value of a given cell of the matrix with a

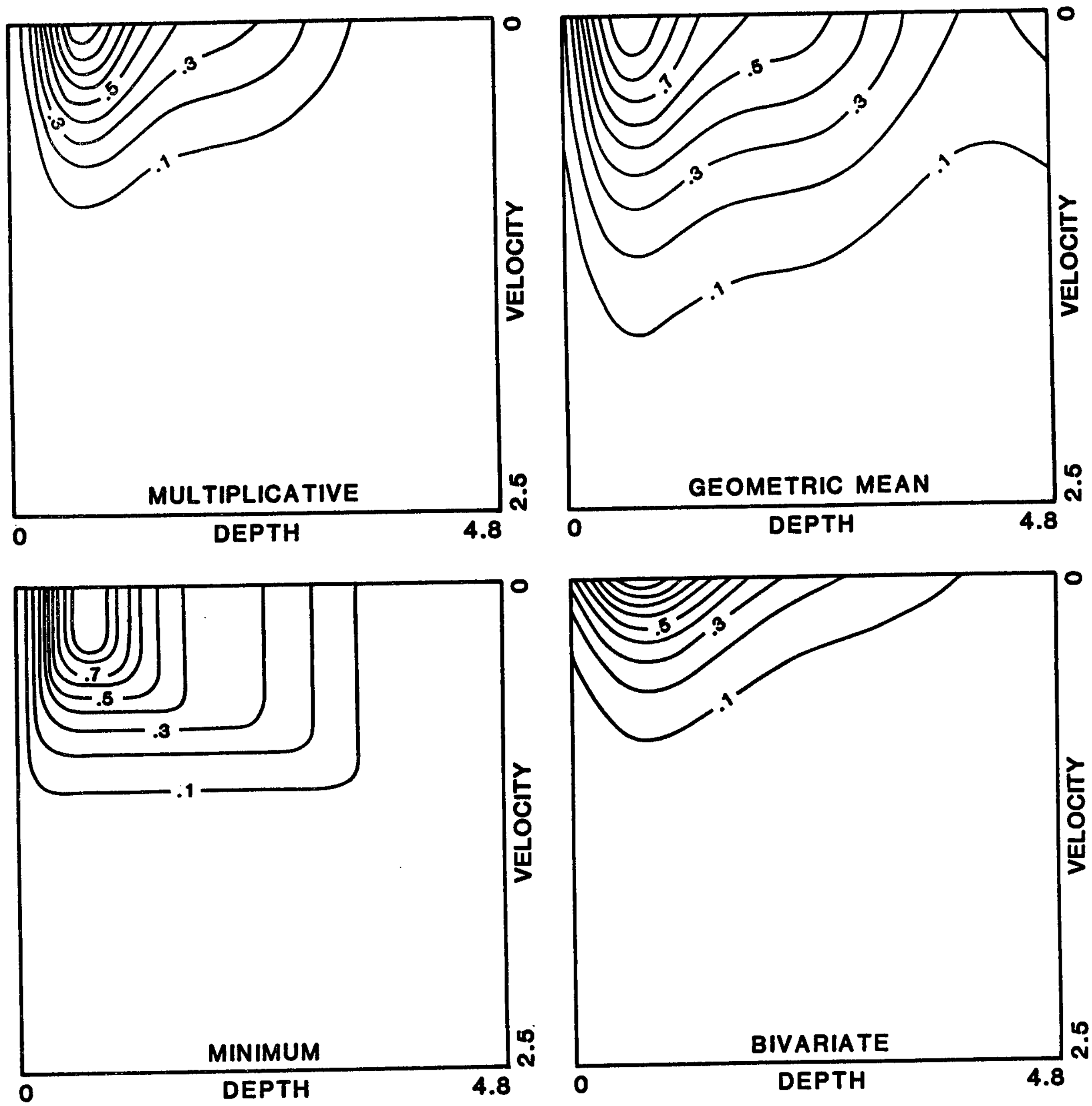

Figure 9. Habitat utilization contour plots for three best-fit univariate models, using multiplicative, geometric mean, and minimum value aggregation techniques, and the bivariate model.

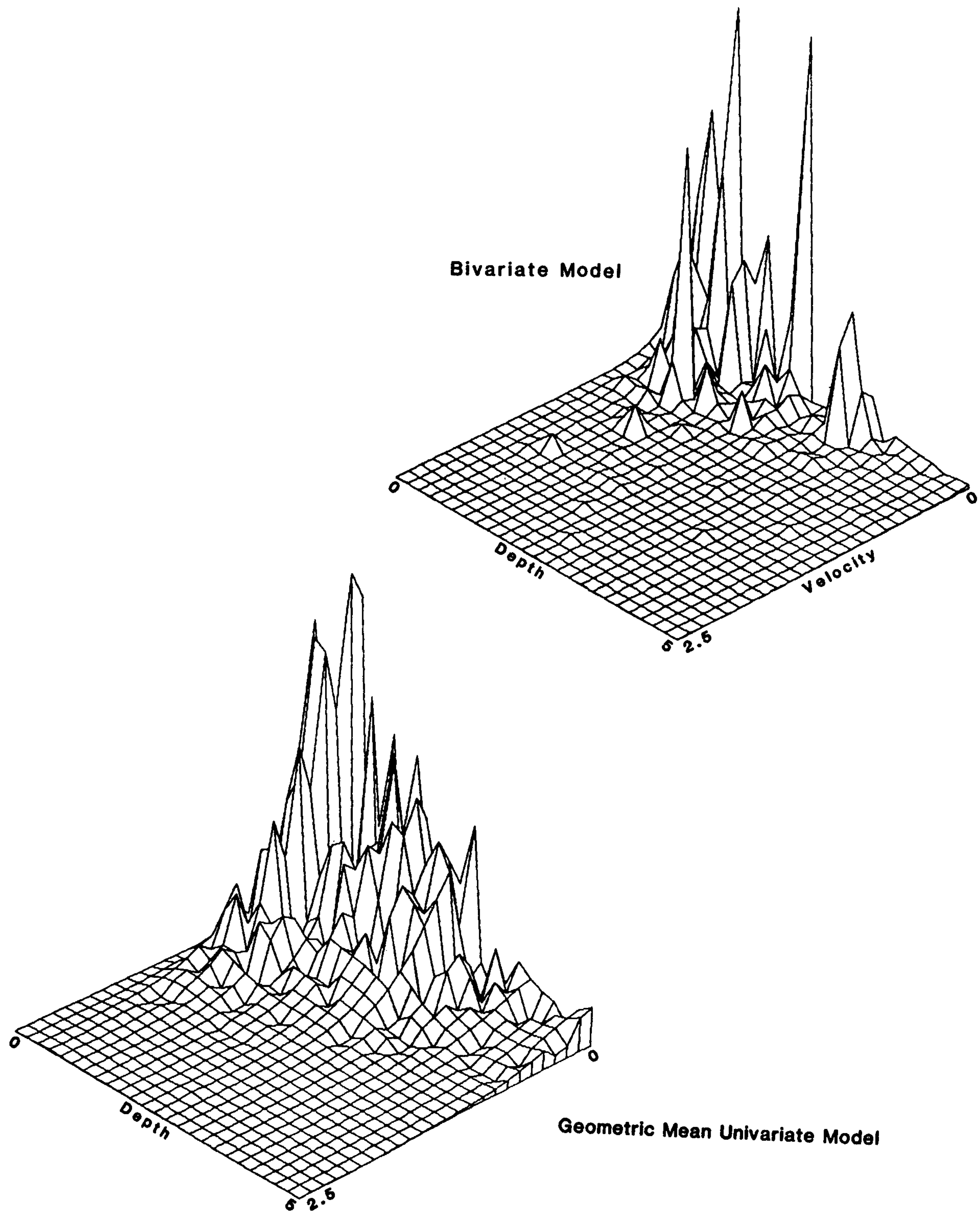

Figure 10. Comparison of cell-specific squared error terms between the bivariate model and the geometric mean univariate model.

weighted average of surrounding cells. The contribution of each surrounding cell is weighted by the inverse of the square of the distance from the cell to the target cell. Thus, cells nearest the target cell have the greatest influence on the weighted average, while cells on the periphery of the radius contribute little to the average. The number of cells contributing to the weighted average is determined by a user-specified radius. A second user-controlled variable is the level of smoothing; by repeatedly running the matrix through the IDS algorithm, varying levels of smoothing can be achieved.

In our investigations with these adult brown trout data, the radius was set to encompass the entire 25 x 25 matrix. Three levels of smoothing were performed: partial, moderate, and complete. The results of the analysis are presented in Figure 11. The utilization response surface generated by the partial smoothing analysis retains many of the secondary peaks present in the original data. As progressively higher levels of smoothing are applied, these peaks tend to disappear, as seen in the moderate smoothing response surface, and by the time complete smoothing is applied, the response surface is devoid of secondary peaks.

While the IDS algorithm produces monotonic response surfaces similar to bivariate curve-fitting techniques, there are certain characteristics of the response surfaces that are less favorable than those of bivariate models. First, the volume beneath the response surfaces of the smoothed models is generally greater than that of bivariate models. The smoothing technique seems to raise the value of cells of low utilization to a greater extent than it depresses the values of the high-utilization cells. The overall effect of this tendency can be visualized by imagining a blanket draped over the original data, with peak values contributing more to the final response surface than the lower values.

The sums of squared errors were computed for the three levels of smoothing:

Level of Smoothing	Partial	Moderate	Complete
Sum of Squares	5.36	22.48	32.60

The magnitude of summed squared error terms for the moderate and complete levels of smoothing are greater than the sum for the geometric mean univariate model, indicating a poor fit to the original data.

Contour plots of the response surface for the smoothing models (Figure 12) also indicate problems with the method. All of the response surfaces for the different levels of smoothing predict fairly high levels of utilization at zero depth. This is due to the effect of cells near the zero-depth cells that show some degree of utilization. This effect could be reduced somewhat by adding extra cells, representing negative depth, with zero levels of utilization, but the rationale for this artificial procedure is not clear.

The investigation into the use of two-dimensional smoothing techniques presented in this report does not represent an exhaustive effort. Although

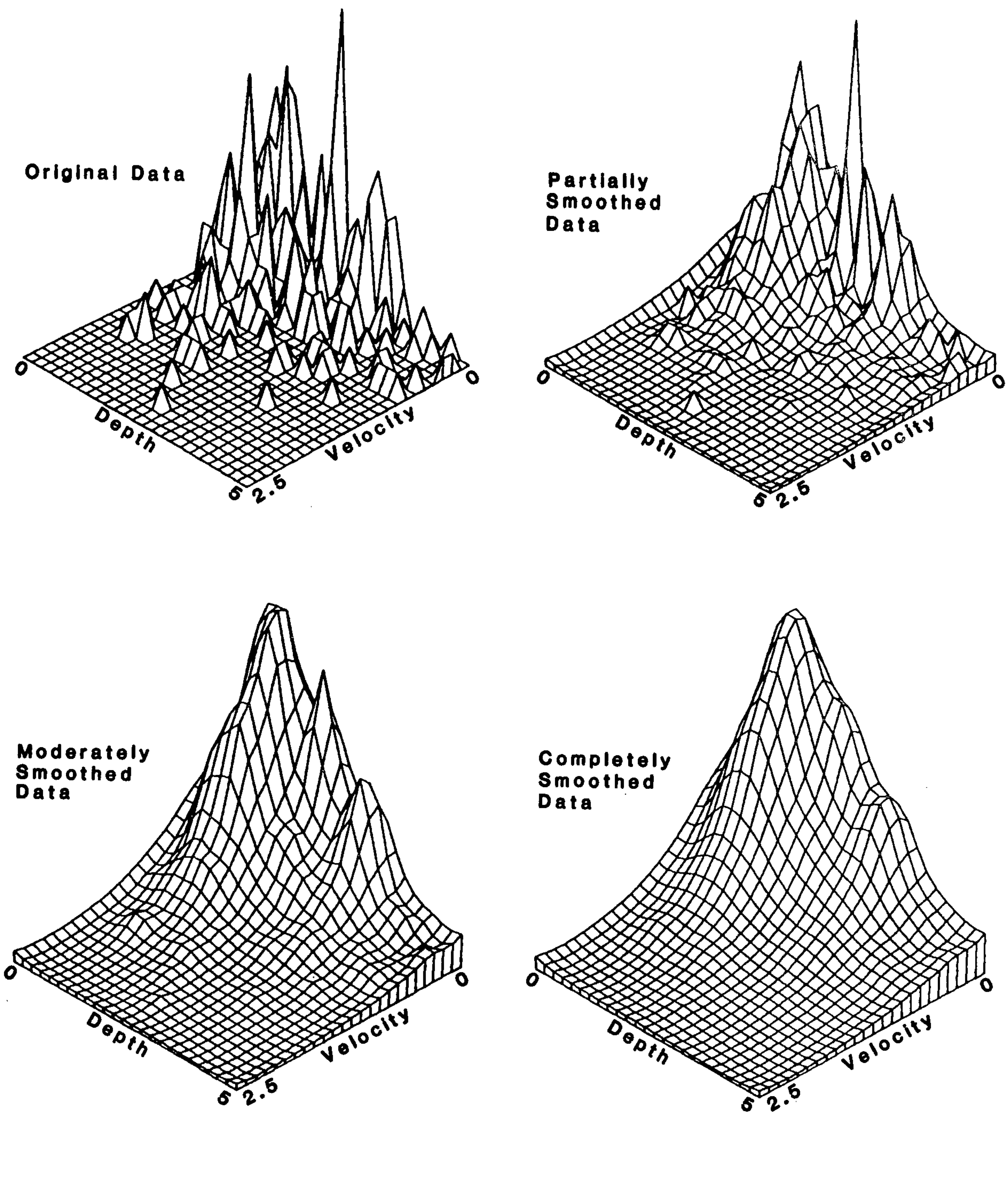

Figure 11. Response surface plots of original data and of partially, moderately, and completely smoothed data produced by application of the inverse-distance-squared smoothing algorithm.

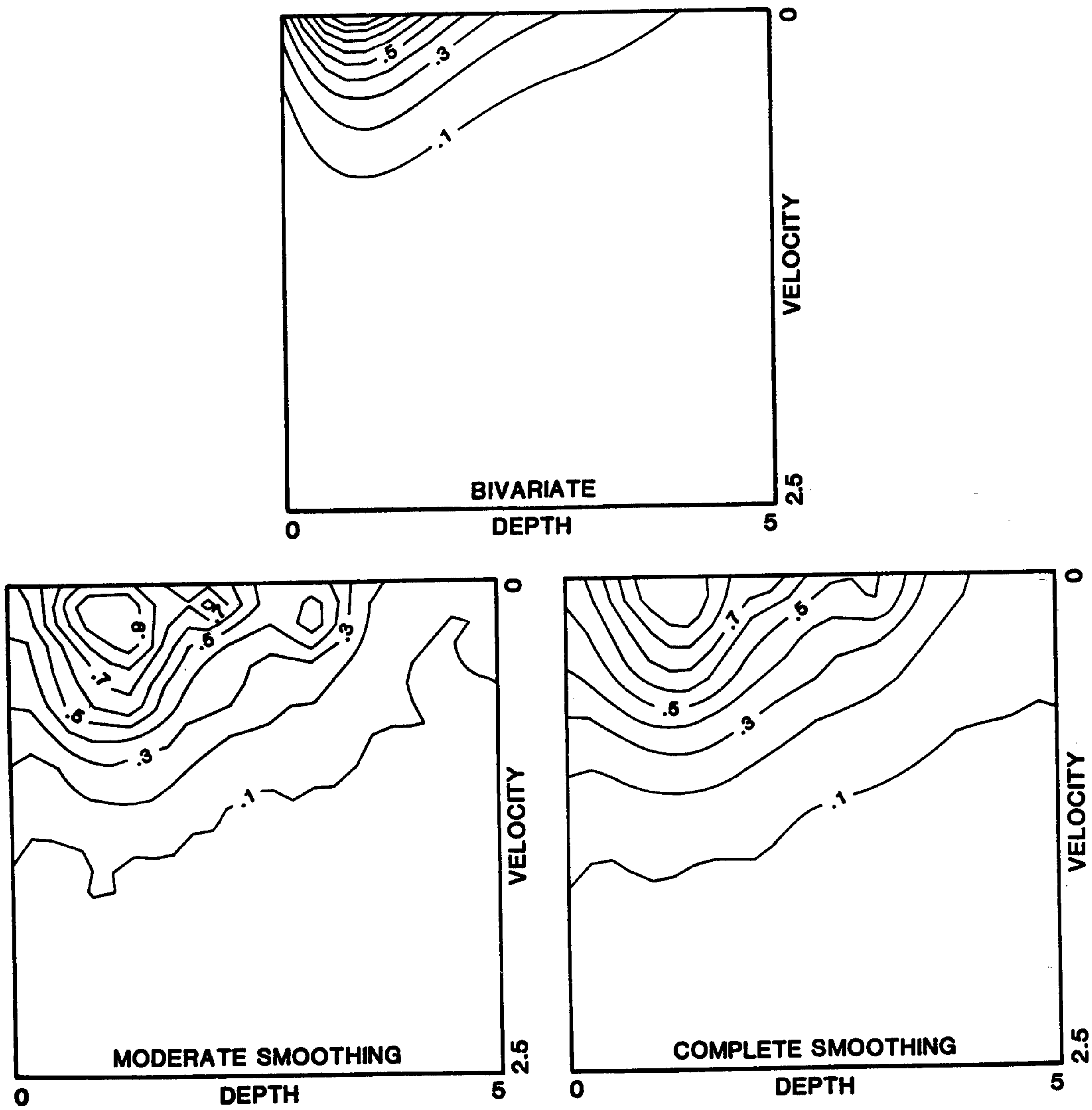

Figure 12. Habitat utilization contour plots for results of moderate and complete smoothing of adult brown trout data using the inverse-distance-squared algorithm and, for comparison, the bivariate contour plot.

usable results, comparable to those of the bivariate and univariate models, were not produced from these analyses, our analysis does not necessarily lead to the conclusion that two-dimensional smoothing techniques should be avoided in this context. Smoothing techniques do have certain advantages over curve-fitting techniques, such as their ability to preserve irregularities in the shape of the original data--something curve-fitting techniques cannot do as well. The success of curve-fitting techniques depends in large part on selecting the right model, or equation. For a given model (univariate or bivariate), curve-fitting techniques only determine the best set of coefficients for the model, not the best functional form describing the relationship between the variables involved.

SUMMARY

A comparison of response surface plots and computed sums of squared errors for a bivariate exponential polynomial model and the multiplicative aggregation of paired univariate models showed minor differences. The similarity between the two models indicates weak interaction in the manner in which adult brown trout utilize water depth and mean column velocity in the study streams. Given these results and the fact that the bivariate model tended to predict small levels of utilization at zero depth, it does not appear advantageous to use a bivariate exponential polynomial model to describe the data.

Comparative studies of univariate aggregation techniques showed the geometric mean algorithm--and to a lesser extent, the minimum value algorithm--to deviate substantially from the distribution of the original data, particularly at high levels of depth and velocity. These results suggest that the geometric mean algorithm does not realistically define the manner in which fish jointly utilize depths and velocity. The multiplicative aggregation technique may be better for applications of the HABTAT model involving univariate depth and velocity functions.

The inverse-distance-squared (IDS) two-dimensional curve-smoothing procedure was found to produce results that substantially deviated from the distribution of the original data. The major problems with the smoothing procedure were high levels of utilization at zero depth and proportionately higher levels of utilization in the area of high velocity and depth. Because of these tendencies, suitability criteria developed with two-dimensional curve-smoothing techniques should always be accompanied by response surface and contour plots to aid in the evaluation of the resulting criteria.

The bivariate exponential polynomial function that was fitted to the data resulted in sums of squared errors similar to those of the multiplicative univariate functions. Interaction between water depth and mean column velocity was not a significant factor. The similarity of sums of squared errors between the two models was supported by the similarity in shape of the response.

ACKNOWLEDGEMENTS

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QUESTION AND ANSWER SESSION

David Hanson

Cheslak: Have you examined the interaction between the accuracy of your histogram and the smoothing technique that you are using? In other words, do you choose your intervals to represent the cases in your raw data set?

Hanson: When you use a smoothing technique, the interval that you choose determines how rough the original dataset is. The rougher it is, the more difficult it is to fit any kind of function to it. If you want to fit all the data points, all you have to use is an n-1 polynomial, and you can fit every point. But, you will end up with a response service that is just as complicated as your dataset. When you choose the smoothing technique you have to go back to the interval size that was originally used. Therefore, our initial lumping of data has influence on what the eventual curve is going to look like. I could have done that some more. I considered going through and lumping the data at different intervals.

Leonard: Is it true that you found that the multiplicative univariate curves, assuming independence, worked as well as bivariate exponential polynomial fit? That being the case, the only time the multiplicative approach would be suspect is when there are significant interactions between the terms in a bivariate distribution.

Hanson: The real question is whether the interaction term is based on selective behavior on the part of the fish or if it's an artifact of the environment that the fish were sampled from. You might want to try to factor the interaction out, but that gets back to the issue from Ken Voos' and Emil Morhardt's papers. It's relatively easy to factor out the interactive term, since it's going to appear in both the numerator and denominator of the suitability equation. If the interaction is caused by environmental availability, then the two should just cancel each other out.

Bovee: One way to handle that problem is to develop univariate distributions for depth and velocity utilization, and perform regressions between depth and velocity for the locations where the fish were located. Then do the same thing between depth and velocity for all of the availability measurements. Statistical tests can be performed to compare the slopes of the two regressions to determine if the utilization cross product terms are coming from the same population of data as the availability cross product terms.

DEVELOPMENT OF A BIVARIATE DEPTH AND VELOCITY SUITABILITY FUNCTION FOR DOLLY VARDEN (SALVELINUS MALMA) JUVENILES

by

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ABSTRACT

A bivariate depth and velocity suitability function has been developed for Dolly Varden (*Salvelinus malma*) juveniles using data collected in tributaries and side channels of the Chakachatna and McArthur River systems near Tyonek, Alaska. Exponential polynomial probability density functions were fit to utilization and availability data as steps in the process of developing the suitability function. The suitability function was developed by accounting for the relative abundance of the depths and velocities that were available to the fish at the time of sampling. The suitability function predicts that mid-depths are suitable at near-zero velocities and lower depths are suitable at higher velocities.

INTRODUCTION

The purpose of this paper is to present a mathematically based approach to the development of multidimensional suitability (preference) functions for a fish species/life stage, which can be used with the Instream Flow Incremental Methodology (IFIM) developed by the Instream Flow and Aquatic Systems Group (IFG) of the U.S. Fish and Wildlife Service. Our use of the term suitability function is as defined by Voos (1981) and Hardy et al. (1982), i.e., a function that represents the suitability of habitat attribute values (e.g., depth and velocity) in providing habitat for a particular fish species/life stage. The type of function to be developed has been referred to as a category III preference criteria function (Bovee 1986). Developing suitability (preference) functions involves collecting data that represent the habitat attribute values utilized by the species/life stage of interest and developing a function that is adjusted to account for the habitat attribute values that were available to the fish during the period of data collection. As previously demonstrated

(Voos 1981), the correction for habitat availability improves the representativeness of the derived suitability function even if that suitability function is to be used exclusively on the stream system from which is was derived.

The functional form chosen was exponential polynomial. This class of functions was chosen for the range of multidimensional shapes that can be represented (Burnham et al. 1980), and because software exists (available through ASB) for fitting these functions. This software was modified slightly to run on microcomputers that use the MS-DOS operating system.

THEORY

Suitability functions, Ψ, (Voos 1981; Hardy et al. 1982) are defined by:

$$\Psi(\vec{x}) = c \, \frac{f_{E|F}(\vec{x})}{f_E(\vec{x})} \tag{1}$$

where $\vec{x}$ = vector of environmental attribute values that may provide fish habitat within a stream segment

$f_{E|F}(\vec{x})$ = the conditional probability density function (pdf) representing the relative utilization of environmental attribute values by the target fish species/life stage within the studied stream

$f_E(\vec{x})$ = the pdf representing the relative availability of environmental attribute values within the studied stream

c = a factor that normalizes the ratio of the two pdf's such that the maximum value of the suitability function is equal to one over the range of habitable environmental attribute values

Suitability functions defined as above are proportional to the probability of finding one or more fish in a stream subunit (i.e., cell), given particular values for the habitat attributes.

Exponential polynomials are useful for representing the pdf's, since they can be readily developed for representing multidimensional data. The software available through the Aquatic Systems Branch, specifically a FORTRAN program called XPOLY, uses the maximum likelihood technique for solving exponential polynomial pdf's of up to five dimensions. The maximum likelihood technique uses the entire data set available without the necessity of computing histogram mass points, and uses a regression technique to fit these mass points. Use

of this type of regression technique can lead to loss of information (e.g., induced data smoothing) and distortion in fitted curves.

DATA COLLECTION

Data defining the habitat availability and habitat utilization of Dolly Varden (Salvelinus malma) were collected in tributaries and side channels of the Chakachamna and McArthur River systems near Tyonek, Alaska, approximately 80 miles west of Anchorage. These data were collected as part of the Chakachamna Hydroelectric Feasibility Study conducted for the Alaska Power Authority. Among the habitat attributes sampled were depth, mean column velocity, stage, object and overhead cover, substrate (modified Brusven index, dominant and subdominant particle sizes, and percent fines), distance from shore, temperature, DO, pH, conductivity, and turbidity. These data were collected for both utilization and availability using a stratified random sampling scheme of (1) stream segmentation, (2) selection of a representative reach within the segment, (3) stratifying the reach by habitat type, (4) apportioning sampling effort within strata based on amount present, and (5) sampling using random selection within habitat types. Availability and utilization data were collected at the same flows. Each sampling segment received equal effort. More than 1,050 complete sets of Dolly Varden juvenile data and more than 950 complete sets of habitat availability data were used for this analysis.

In this paper, only the depth and velocity data have been used in the development of suitability functions.

DEVELOPMENT OF SUITABILITY CURVES

GENERAL APPROACH

An organized approach should be used in the development of suitability curves. This approach should include the following:

(1) initial visual analysis of data (availability and utilization)

 (a) development of single attribute histograms, and
 (b) development of two-attribute histograms or two-attribute frequency contour plots;

(2) development of habitat availability pdf and comparison of derived fit to above visual presentations;

(3) development of habitat utilization pdf and comparison of derived fit to the above visual presentations;

(4) development of suitability function and analysis of visual presentations for representativeness; and

(5) validation of derived suitability function(s) using one or more of the techniques described in Bovee (1986).

Step 1b of our approach permits the identification of any important interaction between attributes. We recommend the use of contour plots (or two-attribute histograms) rather than scattergrams, since a scattergram does not indicate the amount of data that each plotted point represents.

Our experience with using exponential polynomials leads us to present the following rules of thumb:

1. If a noncontinuous attribute, such as substrate, is being analyzed along with other attributes, exponential polynomial pdf's should be developed for the other attributes for individual classes of the noncontinuous variable.

2. The order of the polynomials should be limited to the lowest order that adequately represents each attribute.

3. The order of the availability polynomial should be lower than, or the same as, the order of the utilization polynomial for all attributes.

4. If the highest order coefficient for any attribute is less than zero, the value of the exponential polynomial can get very large if it is ever used to extrapolate beyond the data values it was developed from. We recommend that the polynomial order be increased or decreased until the highest order coefficient is greater than zero.

HABITAT AVAILABILITY

Habitat availability data ranged from 0 to 7 ft depth and 0 to 6 ft/sec velocity. Velocity and depth were significantly correlated, $r = 0.8$ ($P < .01$). A contour plot of the depth and velocity data was developed (Figure 1). In developing this plot, each combined depth/velocity was considered as one observation (count of one), the total frequencies occurring were connected to interpolated, equal frequency points. This type of presentation can be read just as one would read a topographic map; the greatest attribute availability is near 0.6 ft depth and 0.0 ft/sec velocity.

Based on our familiarity with exponential polynomials, we represented this availability distribution with a second order depth and a first order velocity exponential polynomial. The resultant exponential polynomial pdf is represented as:

$$f_E(v,d) = \{\exp[-(1.85v - 0.324d + 0.444d^2 - 0.220vd)]\}/1.105 \qquad (2)$$

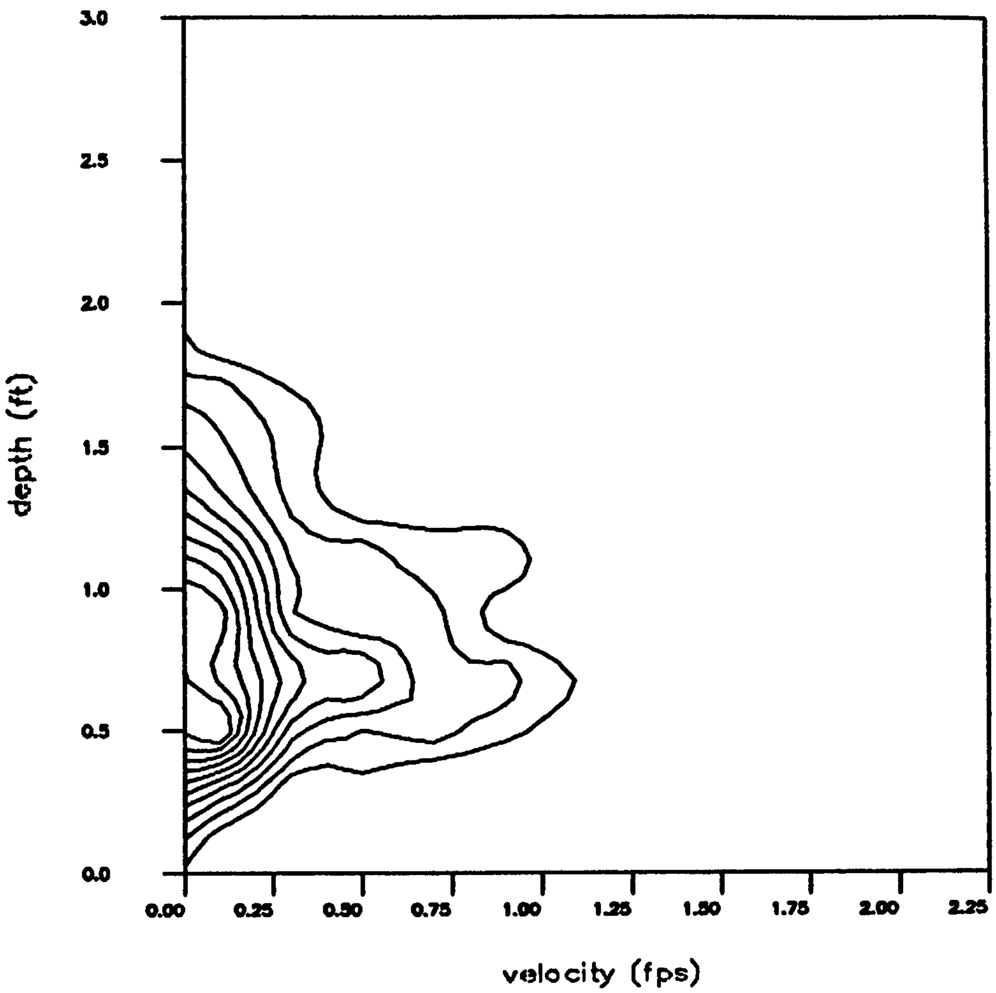

Figure 1. Observed habitat availability.

where v = velocity (ft/sec)

d = depth (ft)

A contour plot of this function is presented as Figure 2. To produce this figure, frequency isopleths were computed by algebraic manipulation of Equation 2. Since different techniques were used to compute the contour lines of the observed data (interpolation of depth/velocity cell mass points) and the fitted function (solution of an algebraic equation), the contours of Figures 1 and 2 cannot be expected to be an exact match, even if the functional fit of the data was an exact fit to the data. The general trends that were observed in Figure 1, a peak frequency at zero velocity, a depth near 0.5 ft, and a rapid reduction in frequency at distance from the peak, are reproduced by the functional fit.

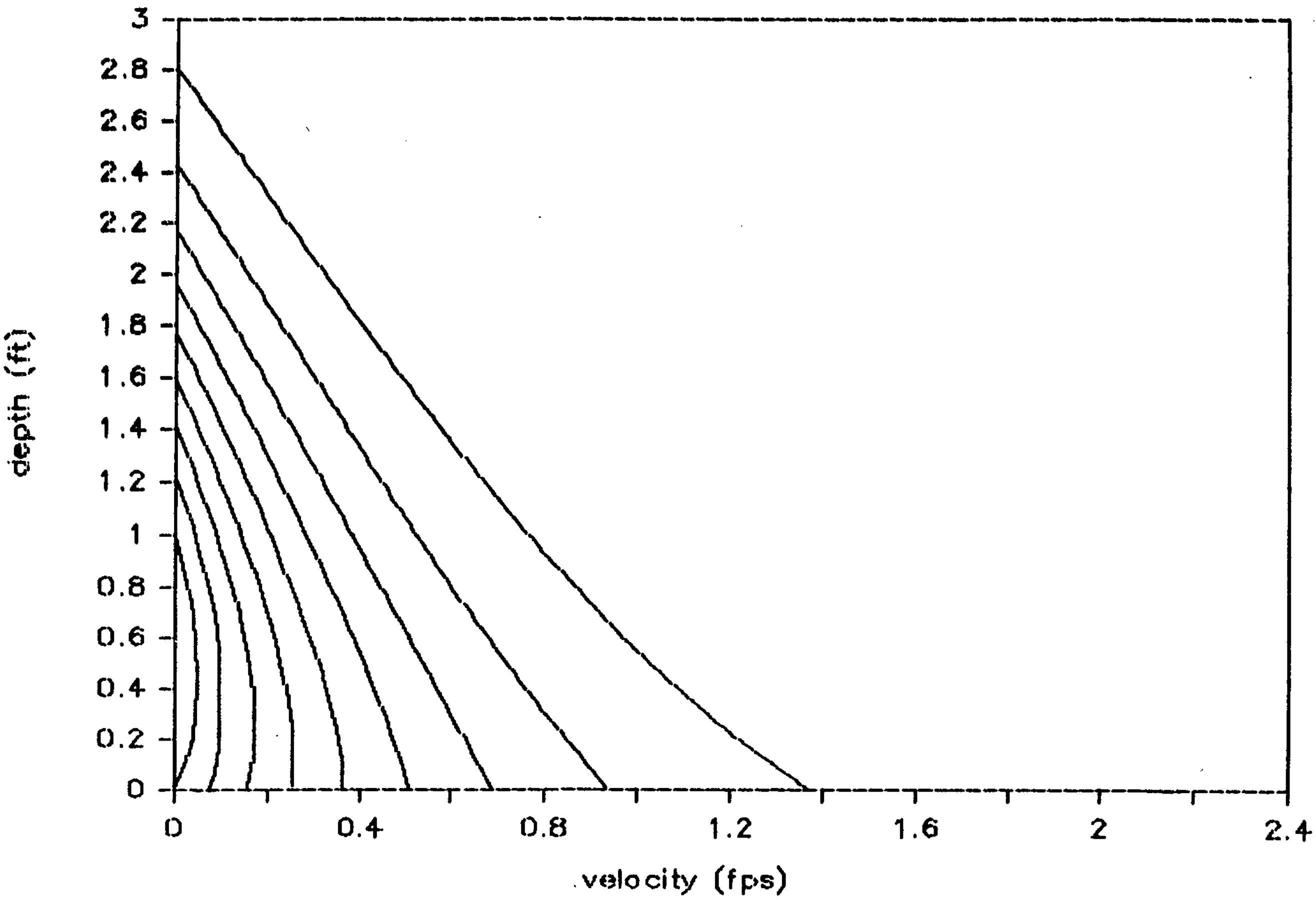

Figure 2. Exponential polynomial fit of habitat availability data.

UTILIZATION

Dolly Varden juveniles were the most numerous and widespread juvenile salmonid found in the study area. Tagging and marking studies indicated that these fish ranged over substantial areas.

Using an approach similar to that used for availability, a depth/velocity utilization contour plot was produced from the depth/velocity data measured where Dolly Varden juveniles were observed (Figure 3). Each fish observation was assigned a count of one; thus, if five juveniles were observed in an area where one depth/velocity measurement was made, the total frequency for this depth/velocity utilization would be five.

Figure 3 illustrates that there was a high utilization of near-zero velocities and two lower peaks of utilization at higher velocities, centered on approximately 0.5 ft/sec and 1.6 ft/sec. Much of the high utilization occurred at the near-zero velocities (compare the availability plot, Figure 1 to Figure 3).

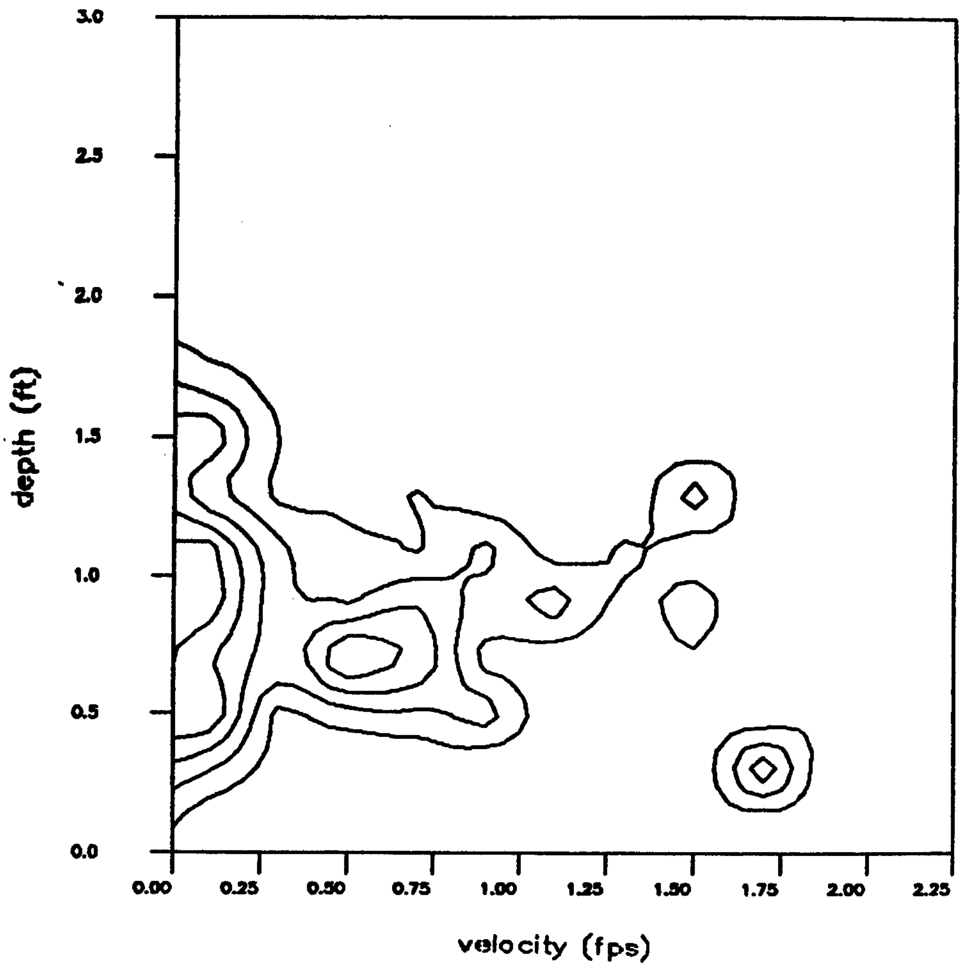

Figure 3. Observed utilization of depth and velocity by juvenile Dolly Varden.

The multiple utilization peaks at the higher velocities are most likely a result of the small depth and velocity cell sizes chosen for accumulating the fish counts rather than a biologically significant phenomenon. We believe, however, that the higher utilization observed at higher velocities (about 1.3 to 1.8 ft/sec) is significant.

The utilization data were edited to include only velocities less than 2 ft/sec. This was done after an initially developed suitability function was weighted toward velocities that, based on our judgment, were too high. This data editing removed about 3% of the total utilization data.

A third order velocity and second order depth exponential polynomial was chosen to fit the utilization data. The resultant pdf is:

$$f_{E|F}(v,d) = \{\exp[-(7.11v - 2.06d - 8.38v^2 + 2.97v^3 + 1.12d^2 + 0.508vd)]\}/1.142 \tag{3}$$

The frequency contours for this function are presented in Figure 4. Utilization, according to this function, would be highest at zero velocity, drop off to an intermediate level, and increase at higher velocities (approximately 0.6 to 1.4 ft/sec). The lower level of utilization frequency predicted with this function than observed at these higher velocities is a result of data smoothing; the two utilization frequency peaks occurring in Figure 3 have been smoothed into a broader, lower frequency peak.

SUITABILITY FUNCTION

According to Equation 1, the suitability function for Dolly Varden juveniles is the normalized ratio of Equation 2 to Equation 3. A convenient feature of exponential polynomial functions is that the ratio of two functions can be obtained by subtracting the denominator coefficients from the like-term, numerator coefficients. Once the coefficients for the exponential polynomial suitability function have been computed, it is necessary to find the maximum value for the function within the range of attribute values for which it is defined. We use an exhaustive search technique because of its general applicability; a more efficient approach would only consider the roots of the first partial derivatives with respect to each attribute and the value of the function at the defined limits of the function.

The resultant suitability function is:

$$\Psi(v,d) = \{\exp[-(5.26v - 1.74d - 8.38v^2 + 2.97v^3 + 0.676d^2 + 0.728vd)]\}/3.047 \qquad (4)$$

The suitability contours of this function (0.1 to 0.9 in 0.1 increments) are presented in Figure 5. This bimodal function would indicate that Dolly Varden juveniles have a high preference for mid-level depths (1.0 to 1.6 ft) at near-zero velocities and an equally high preference for lower depths (0.2 to 0.8 ft) at higher velocities (near 1.5 ft/sec). Division of the utilization function by the availability function resulted in a higher predicted suitability at higher velocities and lower depths than would result from the utilization function. The high utilization at the near-zero depths was reduced in importance in the final suitability function as a result of the high availability of these combined depth, velocity values (e.g., the high utilization was a result of the high abundance of availability).

A bimodal function could be an indication that there were two statistically different populations in our original Dolly Varden juvenile utilization data. We statistically tested the utilization data for significant differences in velocity utilization given various cover types. Using analysis of variance with a null hypothesis that there was no difference between velocities utilized based on associated cover types, we rejected this hypothesis ($p < 0.01$). This implies that different velocities were used when associated with different cover types (e.g., higher velocities were utilized when associated with object cover).

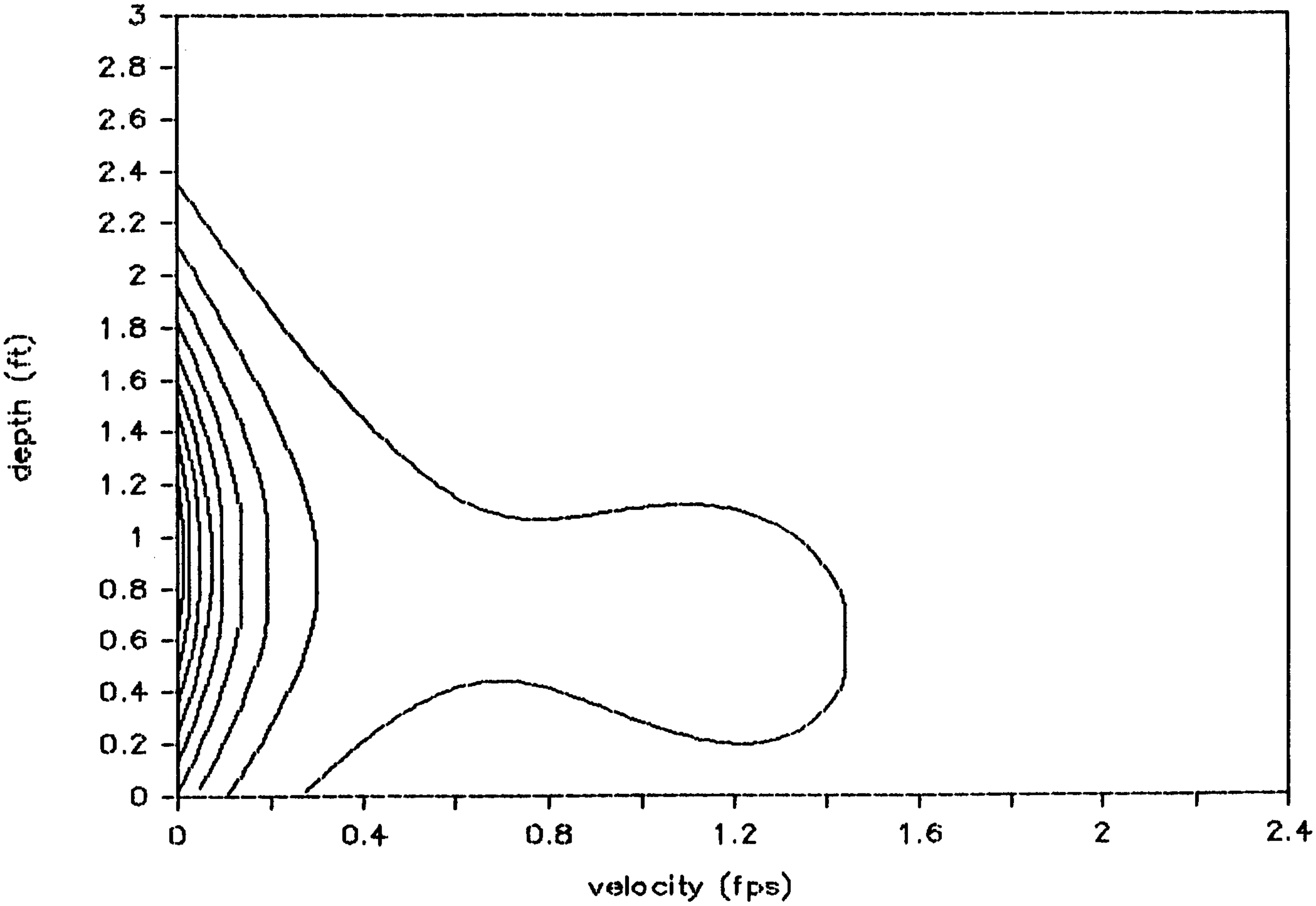

Figure 4. Exponential polynomial fit of depth/velocity utilization data for juvenile Dolly Varden.

The resultant suitability function demonstrates a relatively high interaction between depths and velocity. This resulted from the negative depth/velocity interaction observed in the utilization data set combining with the positive depth/velocity interaction observed in the availability set. The implication is that Dolly Varden juveniles have a preference for higher velocities if these velocities are available at lower depth.

To test the influence of this interaction, an exponential polynomial suitability function was developed without an interaction term by dividing a utilization function developed without an interaction term by an availability function developed without an interaction term. The resultant functions were:

$$f_E\ (v,d) = \{\exp\ [-(1.60v - 0.435d + 0.433d^2)]\}/1.280 \qquad (5)$$

$$f_{E|F}\ (v,d) = \{\exp\ [-(7.64v - 1.71d + 8.42v^2 + 2.98v^3 + 1.09d^2)]\}/0.8487 \qquad (6)$$

$$\Psi\ (v,d) = \{\exp\ [-(6.04v - 1.27d + 8.42v^2 + 2.98v^3 + 0.657d^2)]\}/1.847 \qquad (7)$$

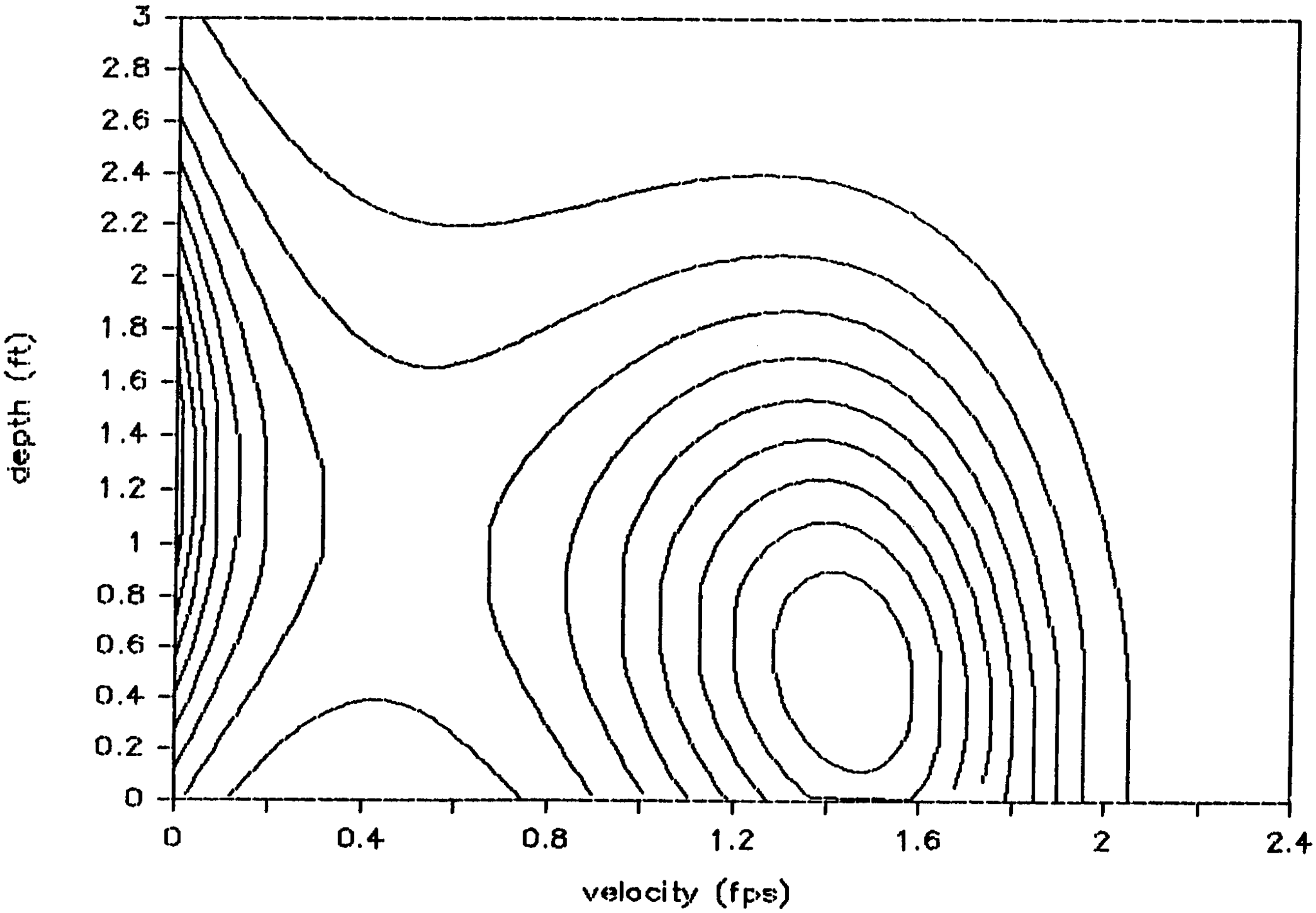

Figure 5. Depth/velocity suitability (preference) function for juvenile Dolly Varden.

This suitability function (Equation 7) was used to compute weighted usable area (WUA) for a shallow, riffle/run-type habitat, and the resultant values were compared with WUA computed by using Equation 4 (Figure 6). For this particular stream segment, the predicted WUA values are approximately equivalent for the simulated flows. Both functions predict the peak values for WUA occurring at similar flows, although the suitability function that considers the depth/velocity interaction predicts peak WUA at a slightly lower flow.

Figure 6 also compares the predicted WUA that would result from using the utilization function (Equation 3 with a normalized factor to limit the maximum value to 1.0). The predicted values of WUA are much lower than predicted with the suitability function that was corrected for available habitat. The peak WUA is at a lower flow than predicted by the suitability function (Equation 4).

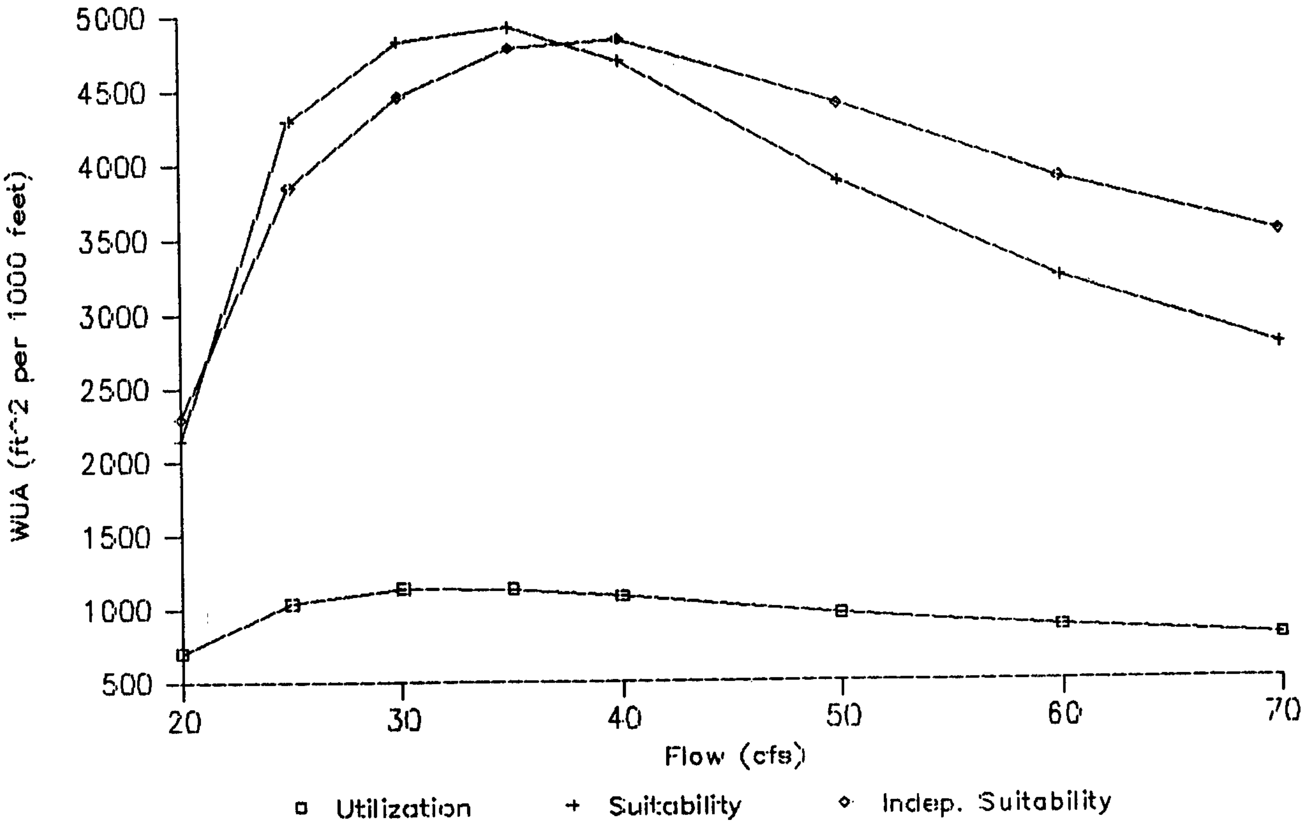

Figure 6. Comparison of weighted usable area versus discharge using utilization, suitability with interactive terms, and suitability without interactive terms.

DISCUSSION

The importance of accounting for habitat availability and for habitat attribute interactions is, most likely, a function of the stream being studied and the target species/life stage. Whether or not these features must be included in the suitability function can only be tested by validating the derived curves to the stream system to which they will be applied. Validating, however, can be a data-intensive, expensive procedure. Since accounting for habitat availability has been shown to be important (e.g., Voos 1981), and since accounting for attribute interactions can be important for certain species (e.g, Prewitt 1982), and since techniques do exist for including these features in derived suitability functions, we recommend that these features be included whenever feasible. It is important to note that accounting for availability produces a suitability (preference) function that is theoretically proportional to the probability of finding one or more fishes in a stream subunit (e.g., depth/velocity cell), given the particular values of the habitat attributes.

In many circumstances, it is necessary to account for availability. These circumstances would include: (1) applying a suitability function that was derived from one stream to another stream, (2) applying a suitability function to flow conditions that were much different than the flows occurring during the utilization data collection, and (3) deriving a suitability function from a system that exhibits strong interactions between the habitat attributes.

There are many curve types that can be used to develop multidimensional suitability functions. Exponential polynomials, as implemented by ASB, have several features that make them a convenient functional form: (1) the software exists for developing exponential polynomials pdf's from availability and utilization data, (2) developing a suitability function from utilization and availability functions is a straight-forward algebraic transformation, (3) exponential polynomial suitability functions have the same functional form as the parent functions, making comparisons easy, (4) interactions among variables can be included in the suitability function, if they are important, and (5) exponential polynomial curve fitting is no more data intensive than any other multivariate technique.

One attribute of the exponential polynomial suitability curve-fitting technique that may require the use of alternate techniques is that the user cannot directly control the shape of the suitability function when it is developed from the utilization and availability functions. The user can, however, control the shape of the final suitability function by selecting the attribute orders of the utilization and availability functions.

The exponential polynomial suitability function software is available; the technique is suitable (has a theoretical basis, and conveniently accounts for habitat availability); and the software/technique can be usable.

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QUESTION AND ANSWER SESSION

Ken Voos

Hanson: What are the differences between the technique you just described and using the same technique with exponential polynomials? What do you see as the difference between your technique and a regression technique using exponential polynomials?

Voos: I'm trying to visualize how you would do a regression fit. There's a theoretical basis for doing it the way we're doing it, because we're fitting probability density functions to utilization data and to availability data. And after dividing these functions you produce a function that is proportional to the probability of finding one or more fish in a cell predicted using PHABSIM. If you do a regression fit, you lose that theoretical basis.

Hanson: Isn't this just an extension of what Bill Slauson was talking about earlier?

Voos: Well, when you do the regression you're not guaranteed of getting a probability density function. There are two attributes that you need. One is that you never go below zero for the probability density function. The other is that the volume or the area under the curve totals to one. If you develop a function using regression, you're not guaranteed these attributes and it would be very unlikely that you'd get both of them at the same time.

Hanson: Let's look at that on a one dimensional front. If we were fitting an exponential polynomial only on velocity, taking depth as an unforced variable for one reason or another, I think most of us fit a curve to the utilization data, fit another curve to the availability data, and divide the utilization curve by the availability curve. Alternatively, we might make the division at the histogram level and then smooth the resultant histogram. I don't see any difference between taking that concept from a one dimensional plane to a two dimensional plane. And I don't believe you need a probability density function, do you?

Voos: Only because of the theoretical basis of it. No, you don't have to. I have not seen any other approach to suitability function development that has a theoretical basis. I'm not totally convinced that any of the other approaches are always that useful. A lot of times they will be because you're dividing one function by another and the differences will balance out in the division because you have to normalize the function in the end anyway. But I'm not really sure.

Lifton: We've used both curves and multivariate functions and very often get the same sorts of answers in terms of weighted usable area. In fact, sometimes even the curves look somewhat similar, but we're losing interactions and some other things when dealt with singly. If interaction is important, it will be lost using univariate curves.

Voos: Dave, there's a very simple answer to your question, in that the available software works that way. It fits probability density functions. It doesn't fit regression to the histogram mass points.

Hanson: What software do you use?

Voos: A program called GOSTAT that I wrote several years ago.

Cheslak: When you say fit, what criteria were used for those programs? Was that chi-square, or residuals, or what kind?

Voos: It's a maximum likelihood solution criteria using Newton-Raphson and Marquart solution techniques.

Cheslak: You're probably minimizing sums of squares, so it's a convergence technique.

Voos: It definitely requires convergence, but there's no regression built into the software. It is maximum likelihood.

VALIDATION OF HABITAT AVAILABILITY DETERMINATIONS BY COMPARING FIELD OBSERVATIONS WITH HYDRAULIC MODEL (IFG-4) OUTPUT

by

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ABSTRACT

Microhabitat availability determinations were made, using a basic random sampling approach, on the Trinity River, Trinity County, California. These data were then used to develop available-habitat frequency distribution curves for depth, velocity, substrate, and instream cover. Concurrent with the field sampling effort, an instream flow analysis was done using standard Instream Flow Incremental Methodology (IFIM) methods. A set of depth and velocity data was then compiled from IFG-4 hydraulic simulation model output. Model output data were compiled first for all cells and then for a sample of randomly selected cells. Frequency distribution curves were developed for these data sets using standard procedures, and the curves were compared to curves developed from field observations.

INTRODUCTION

The Trinity River watershed drains approximately 2,965 square miles in Trinity and Humboldt Counties in northwestern California. A major tributary of the Klamath River, the Trinity River historically has been recognized as a major producer of chinook and coho salmon and steelhead. The Trinity River Division of California's Central Valley Project, constructed in 1963 and

operated by the U.S. Bureau of Reclamation, is the only major water development project in the basin and serves to export water from the Trinity River to the Central Valley of California. The keystones to this project are Lewiston Dam (at river mile 110) and Trinity Dam just upstream. The former represents the upstream limits of anadromous fish migration in the basin. As mitigation for upstream losses, the Trinity River hatchery was constructed at the base of Lewiston Dam, and sufficient flows were to be provided to maintain fish resources.

In December 1980, the U.S. Fish and Wildlife Service and the Bureau of Reclamation reached an agreement to increase releases to the Trinity River below Lewiston Dam to aid in the rehabilitation of anadromous fishery resources. The agreement was approved by the Secretary of the Interior in January 1981. In addition to increasing downstream flow releases for fishery purposes, the agreement provided for a 12-year study to monitor fish habitat response to these increased flows. In December 1983, the U.S. Fish and Wildlife Service completed a "Plan of Study for the Trinity River Flow Evaluation Study." Field work beginning the 12-year evaluation program began in January 1985.

The study includes six major tasks:

(1) annual study plan review and modification,
(2) habitat preference criteria development,
(3) determination of habitat availability and needs,
(4) determination of fish population characteristics and life history relationships,
(5) study coordination, and
(6) reports (progress, findings, and recommendations).

The objective of task 2 is to develop habitat preference criteria quantifying depths, velocities, substrates, and cover requirements for each lifestage and species of salmonid found in the Trinity River. The resulting habitat preference curves will be used in conjunction with hydraulic streamflow data to determine the amount of habitat available for salmon and trout at various streamflows. Data collection for task 2 includes the collection of fish habitat use data using direct observation techniques and the collection of available habitat data using a basic random sampling approach. This report presents the findings associated with task 2.

METHODS

Field sampling of habitat availability was conducted at 14 study sites on the Trinity River between Lewiston Dam and Weitchpec (Figure 1).

Available microhabitat was determined at each study site by taking a minimum of 150 random microhabitat measurements for each discharge recorded during fish habitat use data collection. The sample locations were determined with previously prepared tables of paired random numbers. The first number in

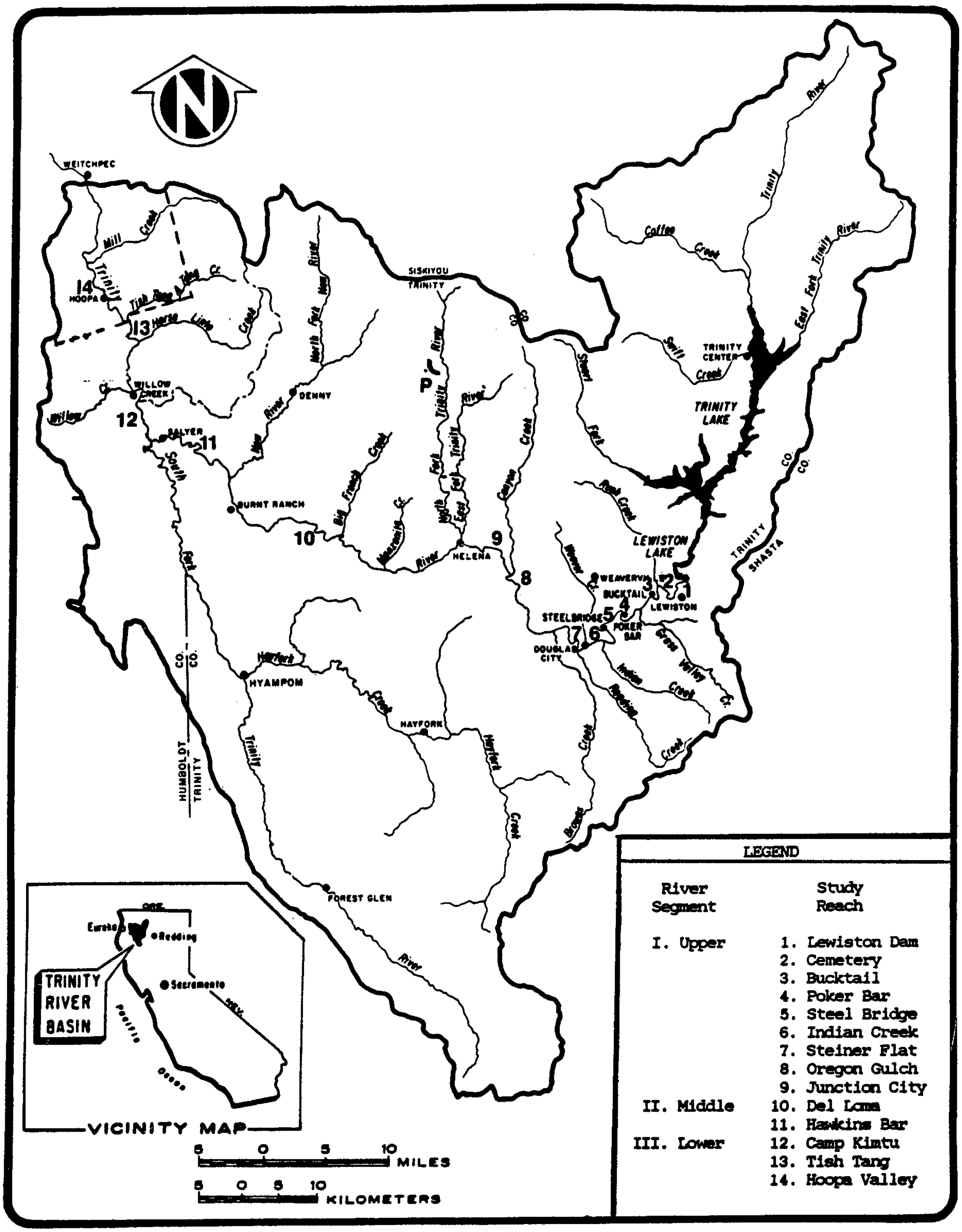


Figure 1. Map of the Trinity River evaluation study area.

the pair represented the distance downstream to the next sampling location, and the second number represented the percent distance across the river channel, yielding the exact location where the sample was to be made.

Data collected during available habitat sampling were essentially the same as the data collected during fish observation sampling and included: (1) stream discharge, (2) habitat type, (3) stream width, (4) total depth, (5) mean column water velocity, (6) substrate, (7) instream cover type, (8) presence or absence of surface turbulence, (9) water temperature, and (10) water visibility.

At each sample location, total depth was measured from the stream bottom to the water's surface. Mean column water velocity was measured at 0.6 depth from the water surface for water less than 2.5 ft deep, and the average of the velocities measured at 0.2 depth and 0.8 depth from the surface was used for water greater than or equal to 2.5 ft deep. Water velocities were measured with either a Marsh McBirney model 201 flow meter or a Price "AA" current meter.

Field collection of random habitat availability data proved to be a slow and laborious process. At least one full day of sampling was required to obtain 150 observations. As an alternative, habitat availability information for depth and velocity was taken from the IFG-4 hydraulic simulation model output to estimate habitat availability at several selected study sites between Lewiston Dam and Steiner Flat (Figure 1). The method that was used to select vertical habitat measurements from the IFG4 model was as follows:

1. The total length of the study site and the distances between each transect were determined, and weighting factors, upstream and downstream, for each transect were established.

2. The length of habitat that each transect represented upstream and downstream was determined by multiplying the distance to the upstream transect by the upstream weighting factor and by multiplying the distance to the downstream transect by the downstream weighting factor. The resulting distances upstream and downstream were then added to obtain the total distance of habitat represented by the transect.

3. The amount of habitat that each transect represented within the total study site was determined by dividing the transect length by the total study site length.

4. The value determined in the previous step was then multiplied by the number of verticals within the wetted area located along the transect and an additional multiplier to determine the number of verticals to be selected from that transect for the habitat availability assessment. The additional multiplier can be any number that yields a total sample size at the desired level (in this case between 100 and 150).

5. The actual verticals (cells) to be used from each transect were then randomly selected.

The method described above is illustrated in Table 1.

All verticals selected from each transect in this process were then pooled together to produce available habitat frequency distribution histograms for the respective study sites.

Table 1. Method of selecting random available habitat measurements from an IFG-4 model output to obtain an estimate of habitat availability on the Trinity River, Trinity County, California, 1986.

LEWISTON DAM SITE

Simulated Flow = 300 cfs

Study Site Length = 2762 ft

Xsec no.	Wt. up	Factor dn	Cell distance Up	Dn	Total	Total / 2762'	x	No. verts.	x 5	No. verts. selected
1	0.0	0.5	0.0	14.0	14.0	.0051		25		1 (0.64)
2	0.5	0.5	14.0	19.5	33.5	.0121		25		2 (1.52)
3	0.5	0.3	19.5	45.0	64.5	.0234		28		3 (3.27)
4	0.7	0.5	105.0	53.0	158.0	.0572		26		7 (7.44)
5	0.5	0.5	53.0	40.5	93.5	.0339		23		4 (3.89)
6	0.5	0.8	40.5	31.2	71.7	.0260		26		3 (3.37)
7	0.2	0.5	7.8	25.0	32.8	.0119		17		1 (1.01)
8	0.5	0.5	25.0	75.0	100.0	.0362		22		4 (3.98)
9	0.5	0.5	75.0	105.0	180.0	.0652		22		7 (7.17)
10	0.5	0.9	105.0	207.0	312.0	.1130		24		14 (13.56)
11	0.1	0.2	23.0	32.6	55.6	.0201		27		3 (2.72)
12	0.8	0.9	130.4	216.0	346.4	.1254		22		14 (13.80)
13	0.1	0.2	24.0	62.2	86.2	.0312		27		4 (4.21)
14	0.8	0.5	248.8	79.0	327.8	.1350		32		19 (18.99)
15	0.5	0.5	79.0	155.0	234.0	.0847		28		12 (11.86)
16	0.5	0.5	155.0	115.0	270.0	.0978		21		10 (10.26)
17	0.5	0.5	115.0	25.0	140.0	.0507		35		9 (8.87)
18	0.5	0.5	25.0	108.5	213.5	.0773		37		14 (14.30)
19	0.5	0.0	108.5	0.0	108.5	.0393		32		6 (6.29)

Total number of verticals selected = 137

DATA ANALYSIS

Habitat availability curves were constructed for total depth and mean column water velocity at each study site from data obtained by both random sampling and selection of verticals from the IFG-4 model output. Two curves were fit from frequency distributions of depth and velocity. Two running averages were then made on the frequency distributions to reduce deviations between adjacent intervals that are apparent on some curves. The resulting averaged distributions were then normalized to a value of one (1) and a curve was fit.

RESULTS

Estimates of habitat availability were calculated for six study sites on the Trinity River, from Lewiston Dam downstream to Steiner Flat. At each of the sites available, habitat curves were constructed for total depth and mean column water velocity from both the random sampling field method and the selection of verticals from the IFG-4 model output. The curves were drawn together on the same graphs for easy comparisons (Figures 2 through 7).

DISCUSSION

When comparing the two habitat availability estimates, one generated by random field sampling and one generated from selection of verticals off of the IFG-4 model output, the available habitat curves for velocity are similar for each study site except the Lewiston Dam and Bucktail sites.

At the Lewiston Dam site, there is an inverse relationship displayed for velocities between 0.8 ft/sec and 2.2 ft/sec. The velocity curves generated from the model show an available habitat value of 0.9 at a velocity of 1.0 ft/sec and a value of 0.3 at 1.8 ft/sec, whereas the random field sampling data indicate a lower value (0.3) at 1.0 ft/sec and a greater value (0.8) for 1.8 ft/sec. A possible explanation for the model's variance from the random field sampling is in the weighting factor values that are assigned each transect in the IFG-4 model. The lowest possible weighting factor that can be assigned a transect is 0.1. When assigning a weighting factor to a riffle transect, for example, a factor of 0.1 may be overestimating the habitat represented by the riffle. In these cases, a weighting factor below 0.1 would be more representative. Should this be the case, too many random verticals would be selected from these riffle transects, thus creating more available habitat at velocities associated with riffles, approximately 1.0 ft/sec. In turn, this overestimation of velocities associated with riffles would cause an underestimation of higher velocities (2.0 ft/sec) found in the more abundant shallow runs, which are present at the dam site.

The two velocity curves for available habitat at the Bucktail site differ between 1.0 ft/sec and 3.0 ft/sec. In this velocity range, the model shows a greater value of available habitat than was observed. In this case, three IFIM transects were located in a pool below a chute in the middle of the study site. While random sampling at the Bucktail site, this section of habitat was not sampled because it was inaccessible to the snorkeler and the raft and

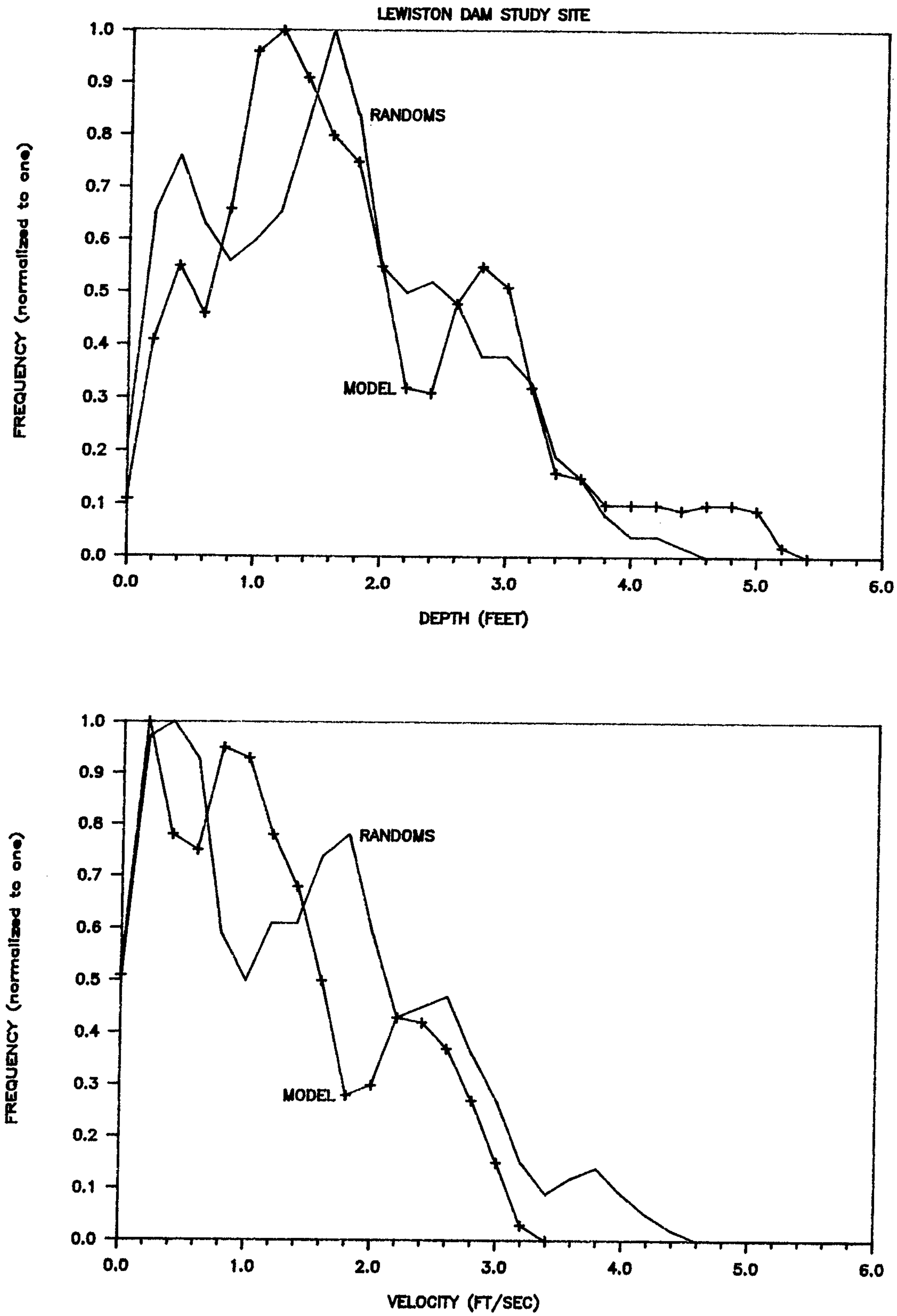


Figure 2. Available habitat for the Lewiston Dam study site, Trinity River Flow Evaluation Study, 1986.

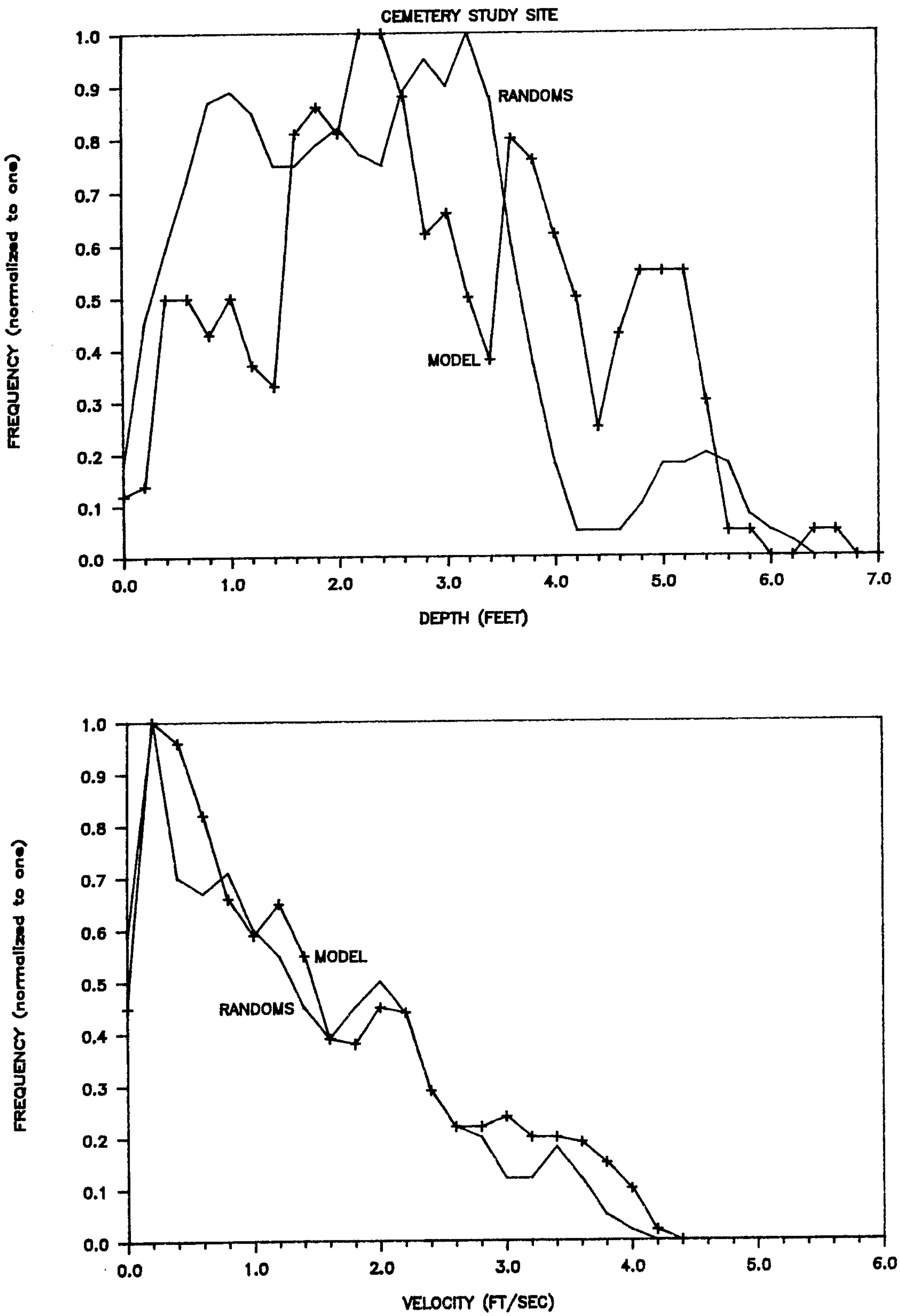
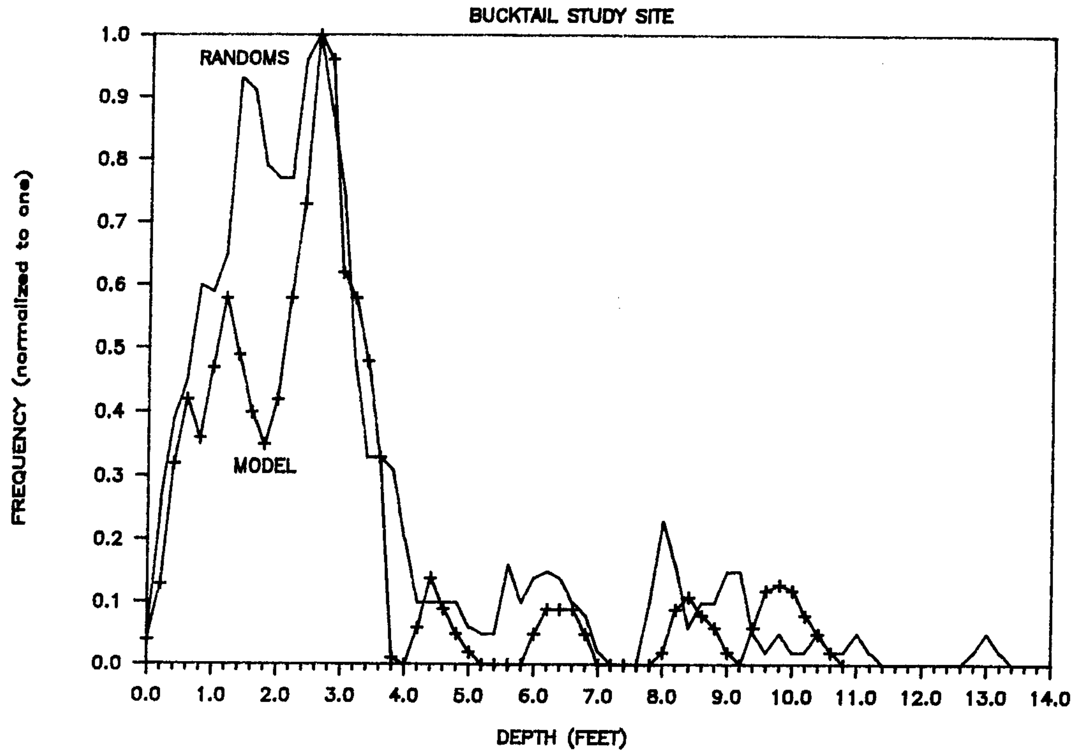


Figure 3. Available habitat for the Cemetery study site, Trinity River Flow Evaluation Study, 1986.



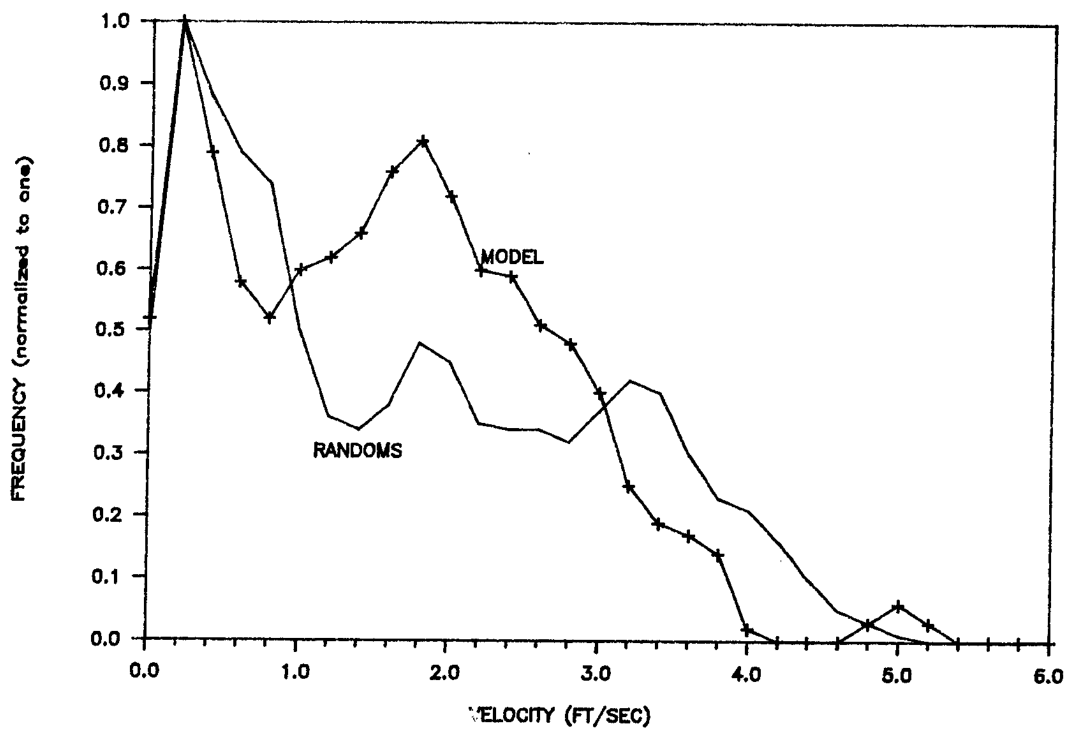
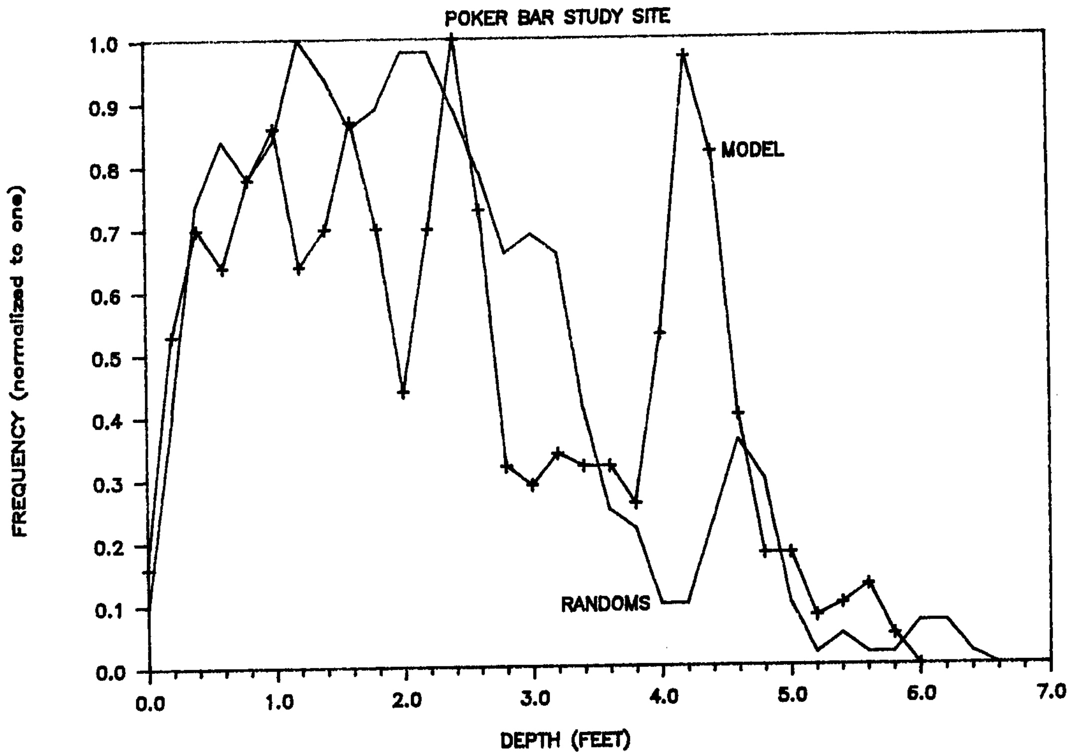


Figure 4. Available habitat for the Bucktail study site, Trinity River Flow Evaluation Study, 1986.



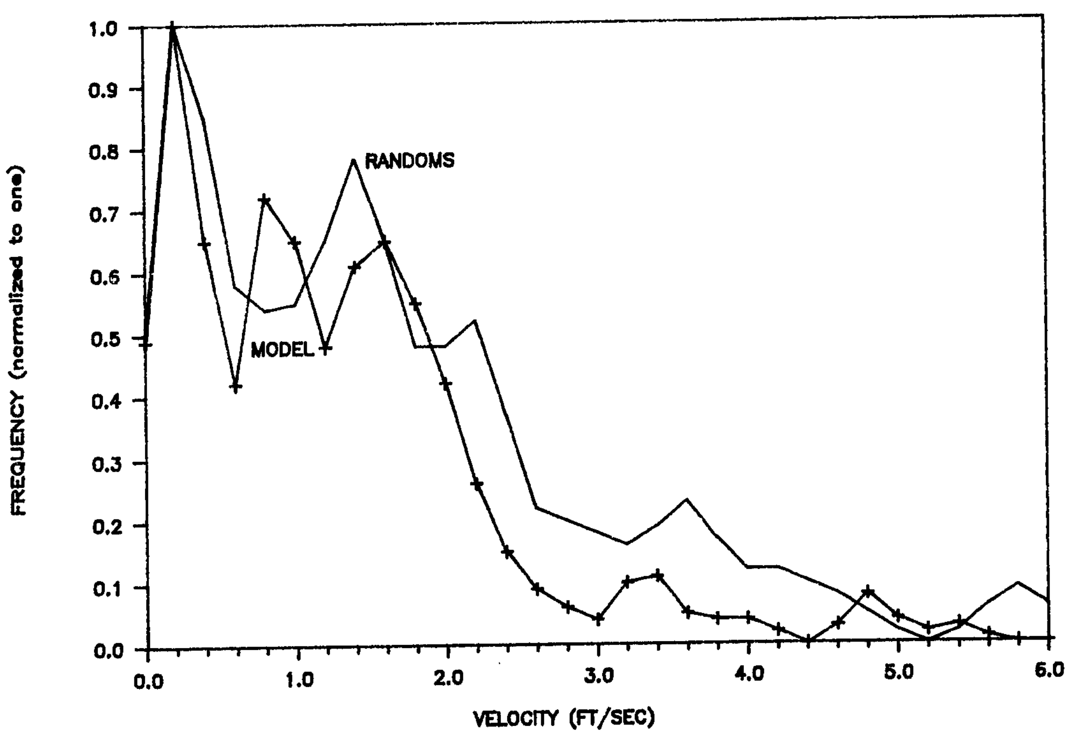
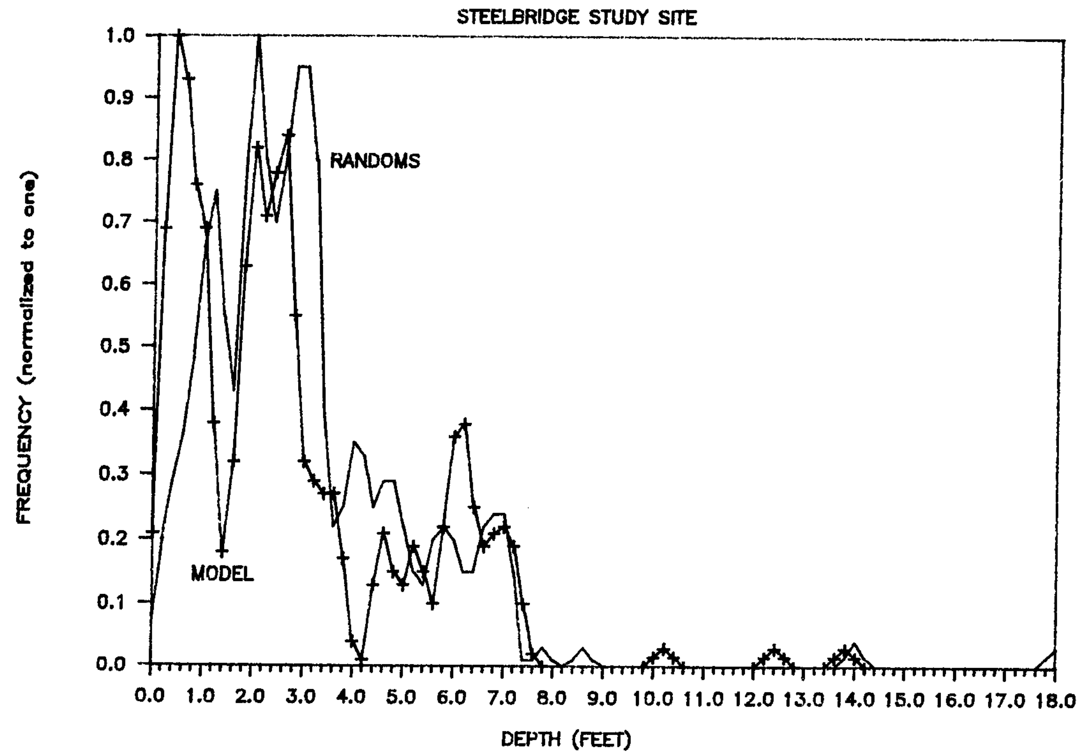


Figure 5. Available habitat for the Poker Bar study site, Trinity River Flow Evaluation Study, 1986.



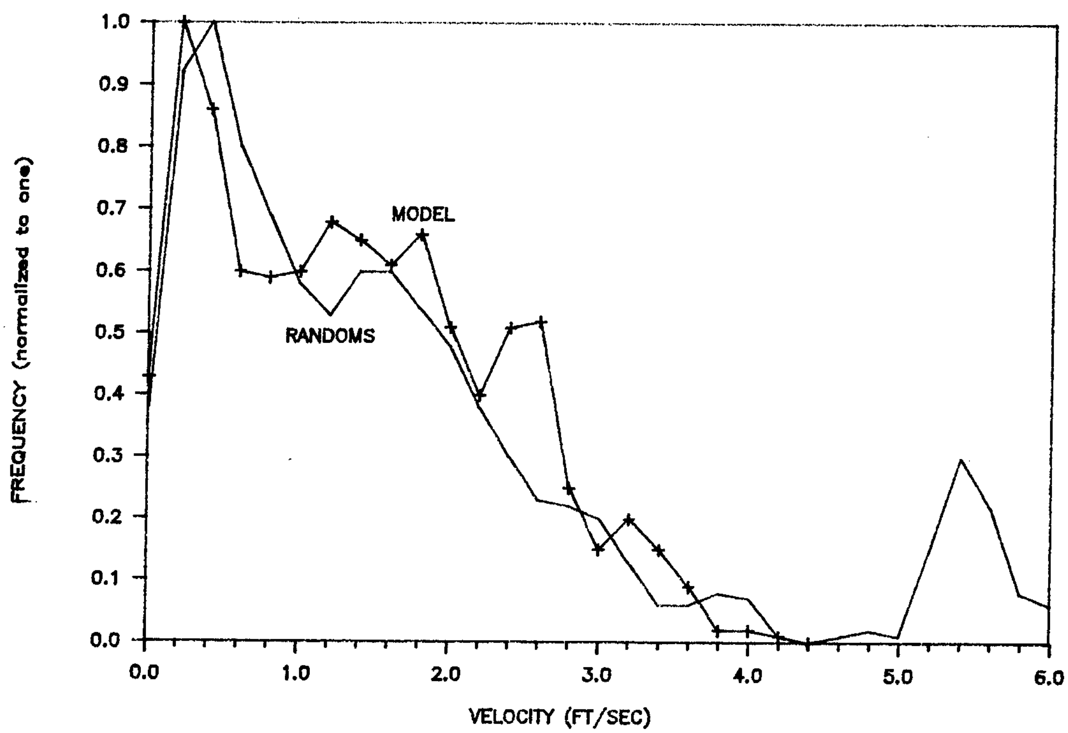


Figure 6. Available habitat for the Steelbridge study site, Trinity River Flow Evaluation Study, 1986.

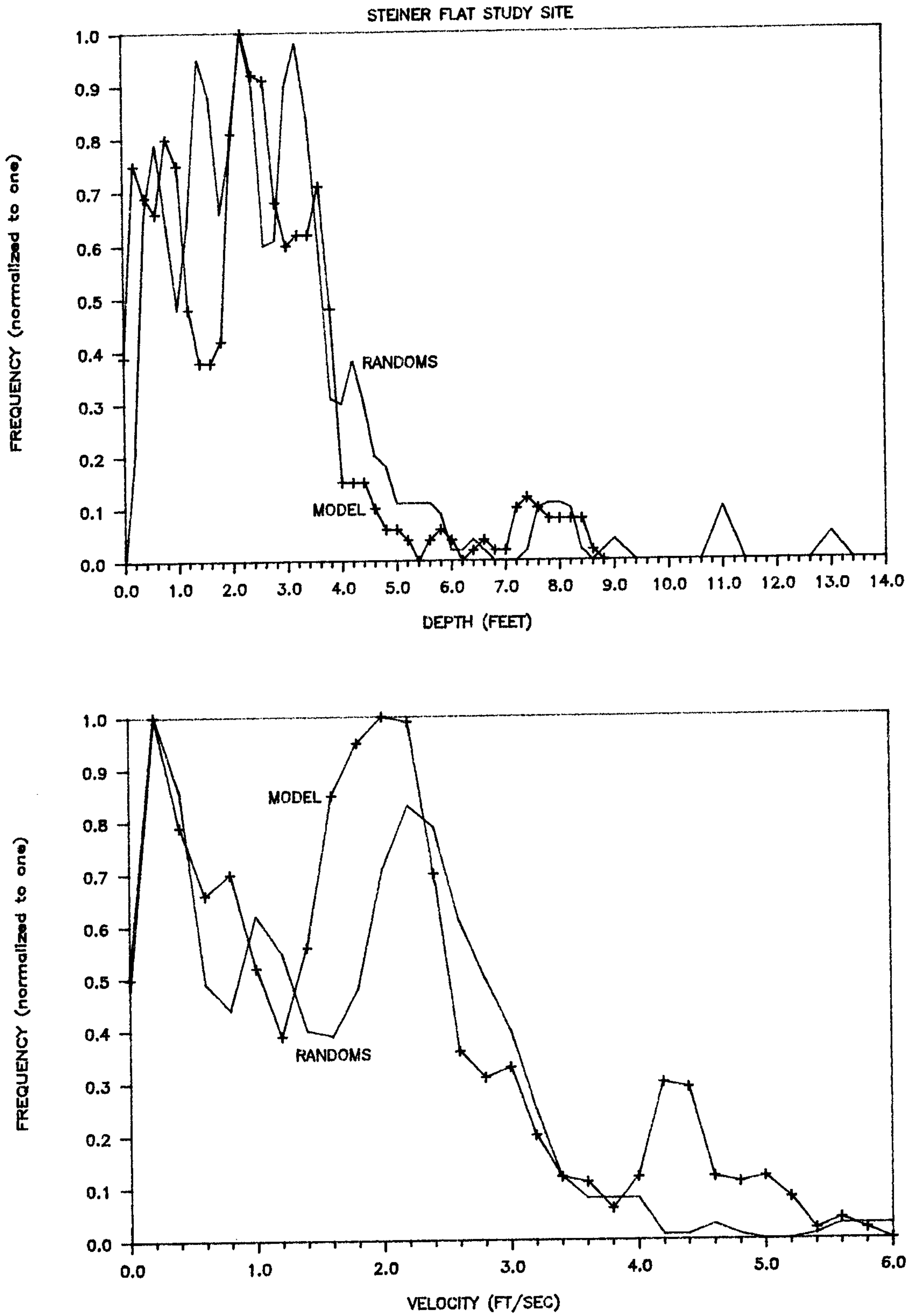


Figure 7. Available habitat for the Steiner Flat study site, Trinity River Flow Evaluation Study, 1986.

equipment (boat, sounding gear, and cable). This may be an explanation of why the model-generated available habitat is greater than the random-generated available habitat at these velocities. The model-generated available habitat for velocity is therefore probably a better estimate for the Bucktail site.

The habitat availability curves for depth generated from the two sampling methods display similar available-habitat estimate values at all but two sites. The available-habitat curves for depth at the Cemetery site differ greatly. This may be explained by the fact that the area sampled by the random observation method is greater in length than the river length within the upper and lower transects of the IFIM study site. What is difficult to explain, however, is why the velocity curves for the Cemetery site so closely resemble one another.

The model-generated available-habitat curve for depth at Poker Bar shows a much greater amount of habitat at depths between 4.0 and 4.6 feet. Random habitat sampling was not conducted on the right channel of a long island located in the center of the study site because preference data have not been collected in this area, however, the model did simulate this channel. If not for this discrepancy, the two available-habitat curves from each method would probably be very similar.

It appears that the major difference between available-habitat curves generated by the two sampling methods were mainly caused by the inability of a snorkeler to sample both deep water and swift water effectively, whereas, the IFIM, with better equipment and great manpower, can effectively sample such habitat types. Another problem evident here is that the preference study site boundaries were defined before the selection of IFIM transects, therefore, the preference study sites are sometimes larger than the area defined by the upper and lower boundaries of the IFIM transects. Elimination of this study site boundary discrepancy in future studies will certainly justify the use of habitat availability curves generated by the IFG-4 for preference curve development. The only problem found with using habitat availability curves generated from the IFG-4 may be the overestimation of some habitat types because of inaccurate weighting factors. This problem can be resolved, however, by inserting more transition-type transects into the study site, which would also provide for a better model of habitat as well.

QUESTION AND ANSWER SESSION

Michael Aceituno

Leonard: You said that your upper three sites showed considerable disagreement, but that you had good agreement at the lower three sites. Was there some difference between those sites in terms of the heterogeneity of the habitat that would suggest that as a cause for the disagreement?

Aceituno: Yes. The two lower sites for which there was good agreement between the two techniques and habitats were very homogeneous. These lower riffles were longer and more evenly spaced than the upper ones. The chance of sampling one of these by random selection was approximately equal to the chance of sampling the same thing in a representative reach. The riffles at the upper end were shorter, actually no more than 15 or 20 ft long out of a study reach that was 1,500 ft long. There were only one or two riffles in that study reach.

Payne: Did you mention what your respective sample sizes were?

Aceituno: Data sets were each about 150 observations.

Hilgert: Did you do any habitat mapping before you selected your study sites and transect sites?

Aceituno: No. Study sites were selected based upon information from several individuals who had spent a lot of years on the river and were familiar with it. Based on their knowledge, we were able to recognize homogeneous reaches within the river and select representative reaches within them.

Question from the floor: How good were your velocity adjustment factors?

Aceituno: I don't remember exactly, but I remember that when we first came out with them we were pleased with the results, so I think they were very good.

Bovee: Any time that we're using PHABSIM as part of a research effort, we have to be a lot more careful in terms of making sure that internal homogeneity is being maintained. I don't think it's quite as critical in operational studies, although we should still strive for homogeneity. This standard has to be much more stringent in research.

Cheslak: A larger sample size, greater than the 150 sample points for habitat availability, will help to smooth out the curve and give better results.

A TEST OF TRANSFERABILITY OF HABITAT UTILIZATION CURVES

by

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ABSTRACT

A method of testing whether utilization or preference functions obtained at one site can be reliably transferred is described. The method is illustrated with data from Hawaiian streams.

INTRODUCTION

Implementation of the Instream Flow Incremental Methodology (IFIM) requires that information on the biology of the target species be expressed in the form of utilization or preference functions. This information, particularly if the species is little known, can be time-consuming and expensive to acquire. If there is sound biological justification, it would be desirable to be able to use information from a single representative survey to provide data for construction of the fish curves. On the other hand, if transferability of habitat utilization data from one reach to another is not justified, biological data from each site would be required. This report presents a method of statistically comparing utilization or preference curves from different sites.

This work was part of a study supported by the U.S. Fish and Wildlife Service, The Division of Water and Land Development (State of Hawaii), and the Water Resources Research Center (University of Hawaii). The goal of the study was to investigate the applicability of IFIM in Hawaii. Two major concerns were hydrology of Hawaiian streams and biology of the stream fishes. Only the second aspect will be dealt with here.

Data from one study reach on each of three streams will be discussed. Two of the streams were typical of larger streams in the State. The study reach on Wainiha River consisted of a wide, low-gradient, simple channel with bed material consisting mostly of cobbles and small boulders. The second study site on a large stream, lower Hanawi, was also located in a low-gradient reach with a simple channel, but the bed material consisted of large boulders, making stream flow more complex. The third study site, Middle Nanue, was a much smaller stream with a very complex channel and braided flow.

The species that will be discussed here is Sicyopterus stimpsonsi, an endemic, diadromous goby. Only adults will be considered. Data on habitat utilization were obtained by observations made while snorkeling. A numbered marker was placed at each spot where a fish was sighted. Habitat data were then obtained at each of the marked locations. Habitat data consisted of mean water column velocity, water depth, and substratum type. Two additional parameters were also measured: "regime" (pools, runs, or riffles) and "position" (side--near the stream bank, center--in the middle of the stream, and margin--the remaining area). In many cases, several fish were located close together. In these situations, the total number of fish at each spot were counted. Data were analyzed both "with repeats," i.e., using the total number of fish counted, and "without repeats," using only a single entry for each marked spot in the stream.

Habitat availability was assessed by measuring the same five parameters at randomly located spots in the study reach.

The habitat utilization and availability data are listed in Tables 1 through 5 and presented graphically in Figures 1 through 9. For each of the aforementioned tables, "q" refers to the percent availability of each variable category (e.g., velocity, depth, substrate). The term "W/O" is the percent frequency of Sicyopterus stimpsoni, without repeats (i.e., only a single record at each citing location). The term "W" is the percent frequency of S. stimpsoni, with repeats, which refers to the total number of fish at each citing location. Levels of significance on Tables 1-5 are delineated as follows: NS indicates non-significance; a single asterisk indicates significance between 0.05 and 0.01; a double asterisk indicates significance between 0.01 and 0.001; a triple asterisk indicates significance less than 0.001.

Utilization and preference curves were developed according to the methods outlined in Bovee (1986). For illustration, preference histograms for one of the study reaches are presented in Figures 10 through 12.

TRANSFERABILITY OF PREFERENCE FUNCTIONS BETWEEN STREAMS

There is no accepted methodology for the transfer of preference functions between streams. Answers to questions of this sort are currently of central interest in theoretical ecology. The basic ecological question we are setting out to answer is: Can an organism's habitat utilization patterns in a

Table 1. Summary of velocity utilization and availability data for Sicyopterus stimpsoni in three Hawaiian streams.

Velocity fps	Lower Hanawi q	Lower Hanawi W/O	Lower Hanawi W/	Wainiha q	Wainiha W/O	Wainiha W/	Middle Nanue q	Middle Nanue W/O	Middle Nanue W/
0.063	20.5	3.1	2.0	4.3	0.0	0.0	26.0	14.9	20.2
0.188	11.8	21.5	26.9	5.1	2.8	1.3	15.6	10.8	7.3
0.313	10.2	6.2	8.3	4.3	0.0	0.0	14.6	18.9	20.2
0.438	7.9	13.8	11.9	4.0	11.1	31.2	8.3	6.8	5.5
0.563	9.4	7.7	10.3	5.9	2.8	3.9	8.3	8.1	9.2
0.688	5.5	0.0	0.8	5.1	0.0	0.0	3.1	2.7	2.8
0.813	6.3	7.7	4.7	5.5	5.6	3.9	6.3	5.4	6.4
0.938	3.9	6.2	9.9	3.6	11.1	5.2	2.1	8.1	8.3
1.063	1.6	4.6	4.7	6.7	11.1	10.4	1.0	1.4	0.9
1.188	3.1	4.6	3.2	5.5	8.3	6.5	2.1	5.4	4.6
1.375	2.4	6.2	4.7	11.1	16.7	13.0	2.1	2.7	2.8
1.626	3.1	6.2	4.3	14.6	11.1	10.4	2.1	2.7	1.8
2.001	3.1	4.6	2.8	13.4	13.9	10.4	2.1	6.8	6.4
2.563	3.1	6.2	5.1	5.1	5.6	3.8	3.1	2.7	1.8
3.188	3.9	1.5	0.4	4.3	0.0	0.0	2.1	1.4	0.9
4.563	3.9	0.0	0.0	1.2	0.0	0.0	1.0	1.4	0.9
N	127	65	253	253	36	77	96	74	109

Kolmogorov-Smirnov Utilization versus Availability

	Lower Hanawi W/O	Lower Hanawi W/	Wainiha W/O	Wainiha W/	Middle Nanue W/O	Middle Nanue W/
Dmax	.174	.185	.122	.147	.160	.141
significance	NS	**	NS	NS	NS	NS

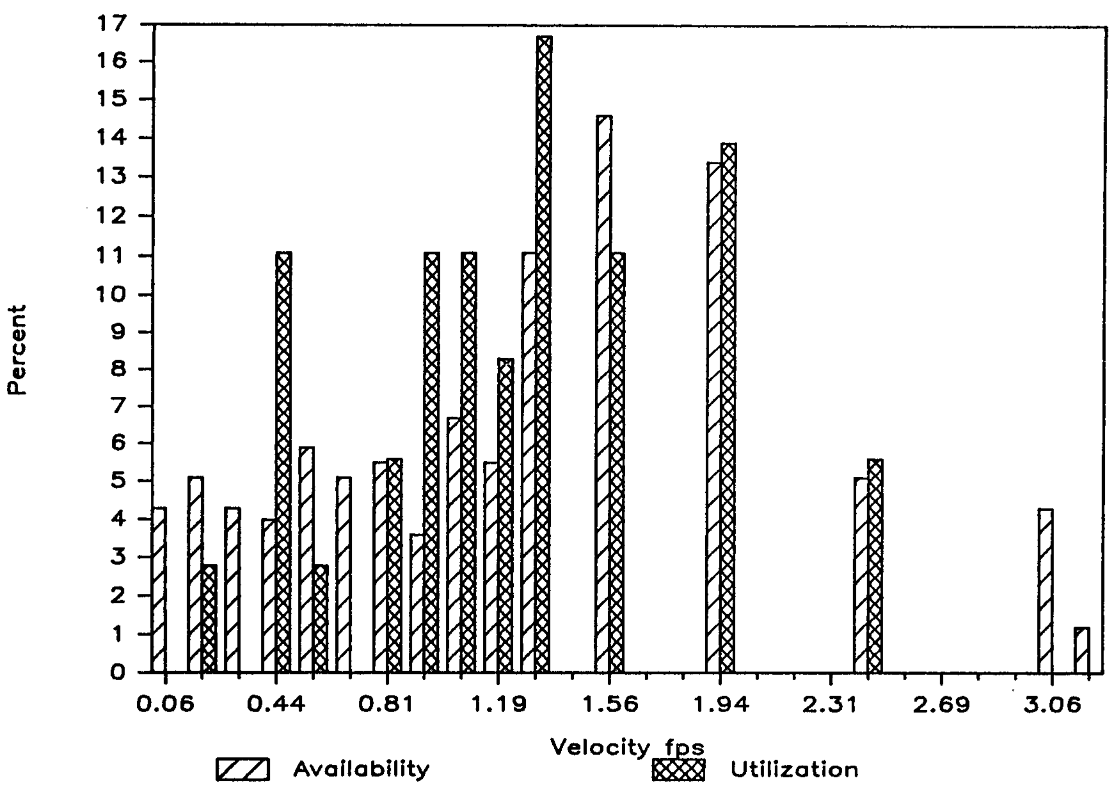

Figure 1. Velocity utilization vs. availability for S. stimpsoni in the Wainiha River, without repeats.

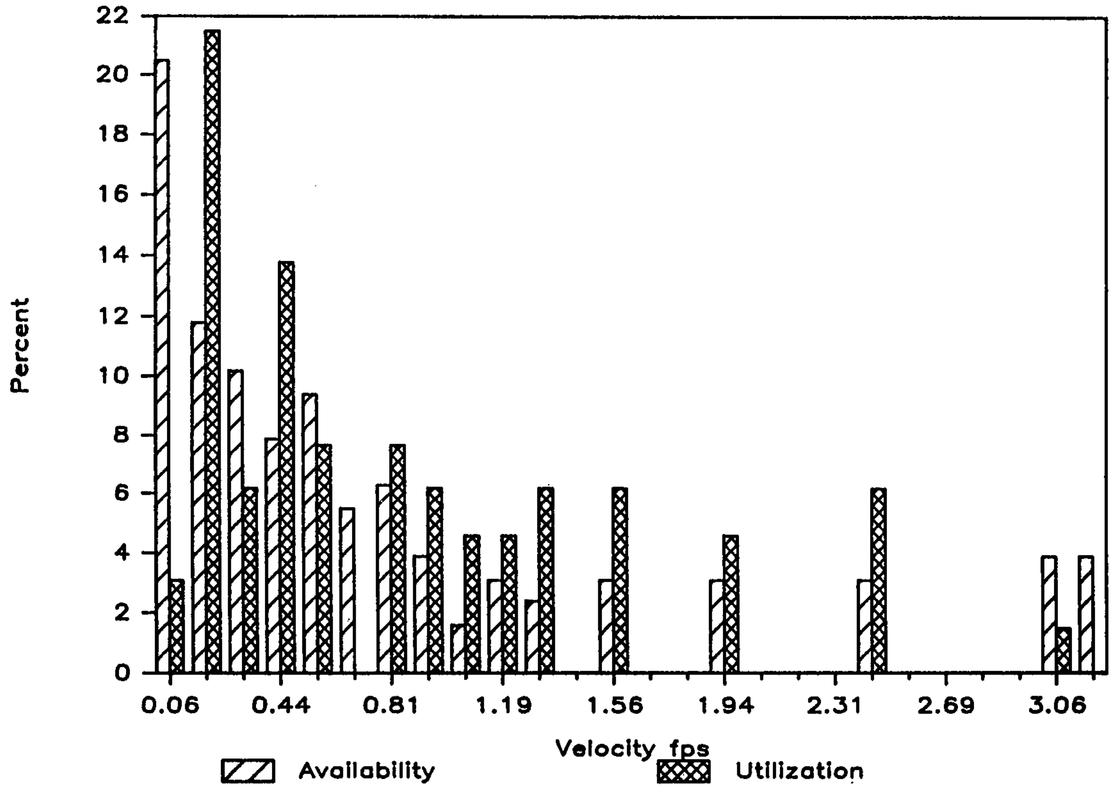

Figure 2. Velocity utilization vs. availability for S. stimpsoni in the lower Hanawi River, without repeats.

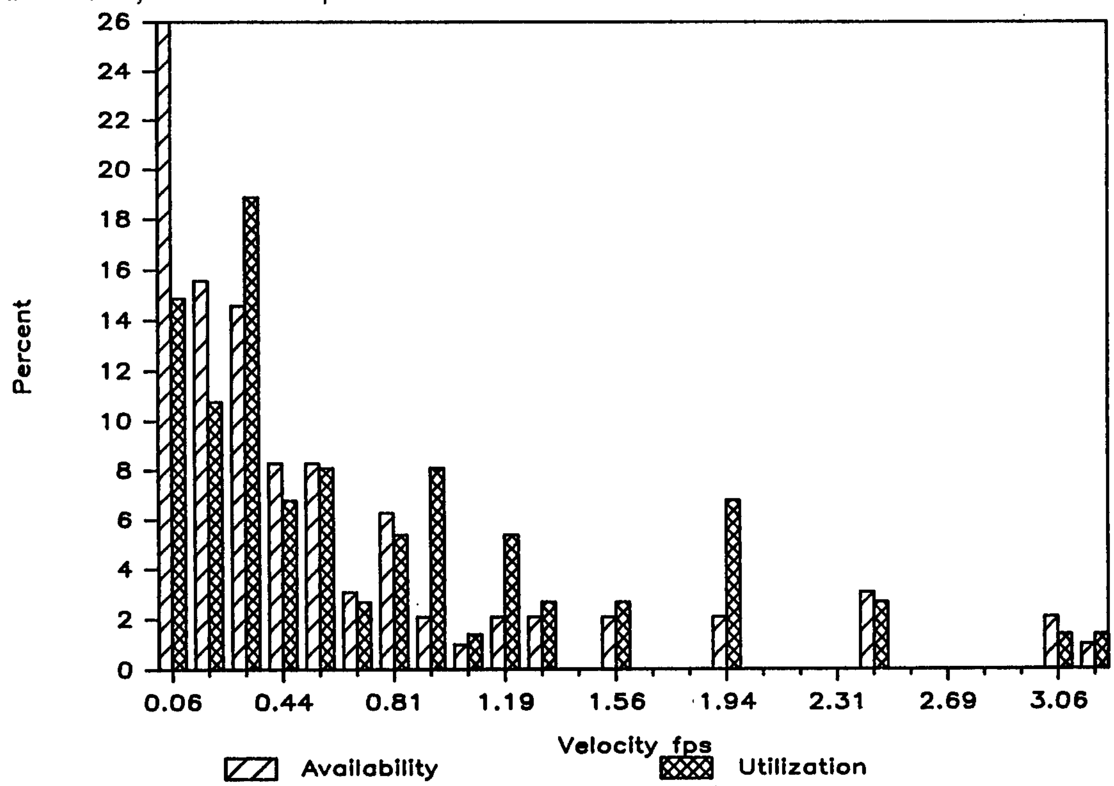

Figure 3. Velocity utilization vs. availability for S. stimpsoni in the middle Nanue River, without repeats.

Table 2. Summary of depth utilization and availability data for S. stimpsoni in three Hawaiian streams.

Depth ft	Lower Hanawi			Wainiha			Middle Nanue		
	q	W/O	W/	q	W/O	W/	q	W/O	W/
0.125	8.7	0.0	0.0	2.8	0.0	0.0	17.7	1.4	0.9
0.375	7.9	1.5	4.3	6.3	0.0	0.0	16.7	2.7	1.8
0.625	15.7	7.7	5.9	8.7	8.3	3.9	16.7	10.8	9.2
0.875	11.0	18.5	13.8	9.1	13.9	1.7	9.4	12.2	13.8
1.125	17.3	20.0	14.6	13.0	22.2	10.3	11.5	21.6	22.0
1.375	6.3	13.8	15.0	12.3	16.7	49.5	8.3	13.5	18.3
1.625	12.6	13.8	12.6	19.8	13.9	11.7	4.2	12.2	13.8
1.875	5.5	9.2	14.6	7.5	8.3	15.2	3.1	6.8	5.5
2.125	0.8	4.6	4.0	6.7	5.6	2.6	2.1	10.0	8.3
2.375	3.1	1.5	3.2	4.0	2.8	1.3	3.1	4.1	3.7
2.625	0.8	4.6	3.2	3.6	2.8	1.3	1.0	2.7	1.8
2.875	0.8	1.5	2.0	2.0	2.8	1.3	2.1	1.4	0.9
3.125	2.4	1.5	2.8	2.8	0.0	0.0	2.1	0.0	0.0
3.375	0.0	0.0	0.0	1.2	0.0	0.0	1.0	0.0	0.0
4.500	7.1	1.5	4.0	0.4	2.8	1.3	1.0	0.0	0.0
N	127	65	253	253	36	77	96	74	109

Kolmogorov-Smirnov: Use versus Availability

	Lower Hanawi W/O	Lower Hanawi W/	Wainiha W/O	Wainiha W/	Middle Nanue W/O	Middle Nanue W/
Dmax	.231	.220	.095	232	.362	.391
significance	*	***	NS	**	***	***

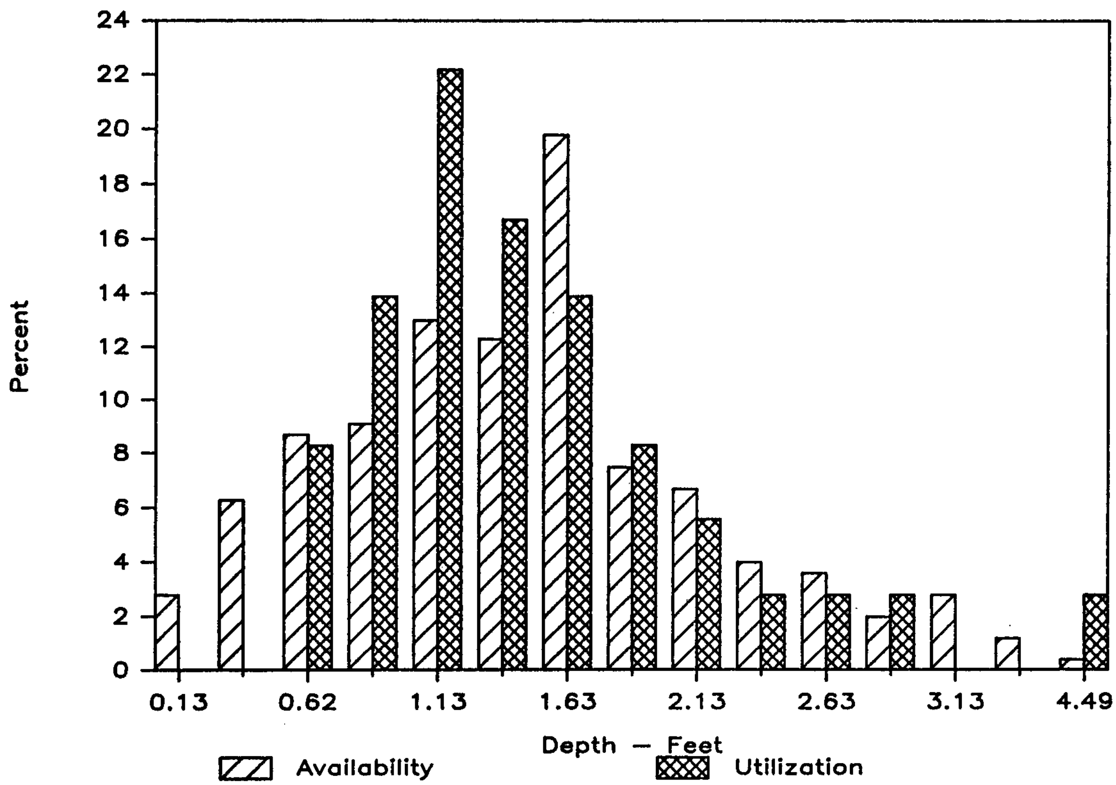

Figure 4. Depth utilization vs. availability for S. stimpsoni in the Wainiha River, without repeats.

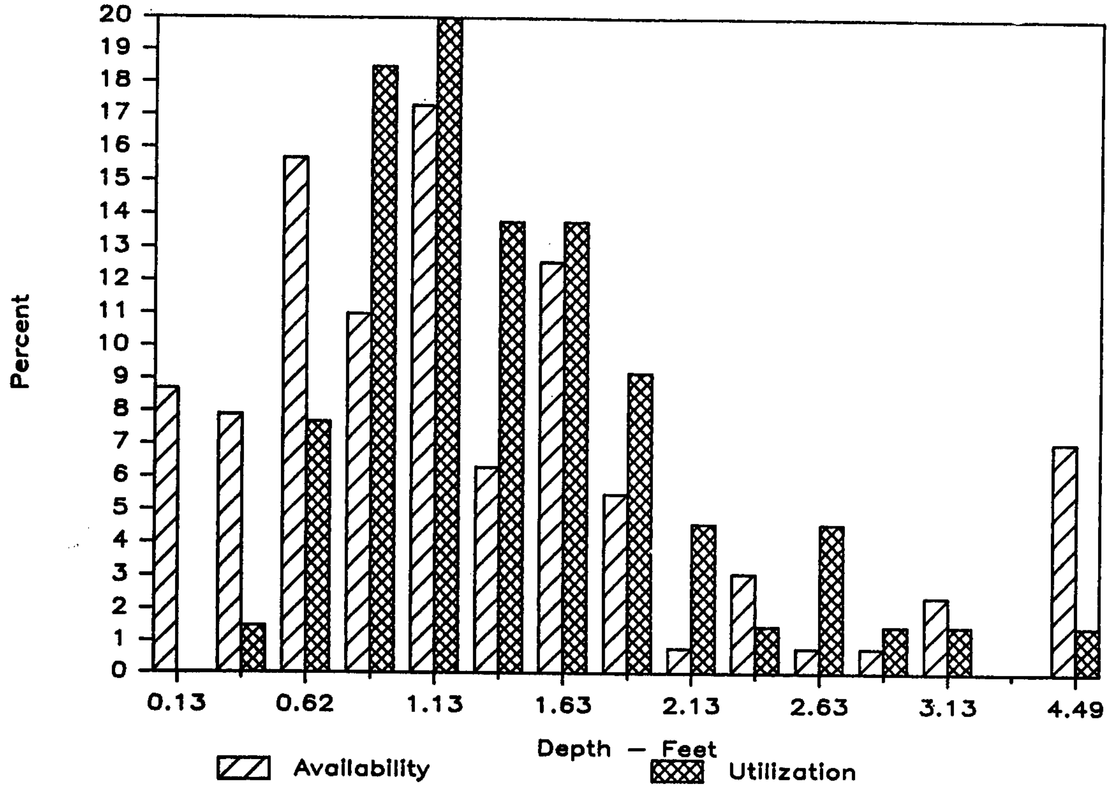

Figure 5. Depth utilization vs. availability for S. stimpsoni in the lower Hanawi River, without repeats.

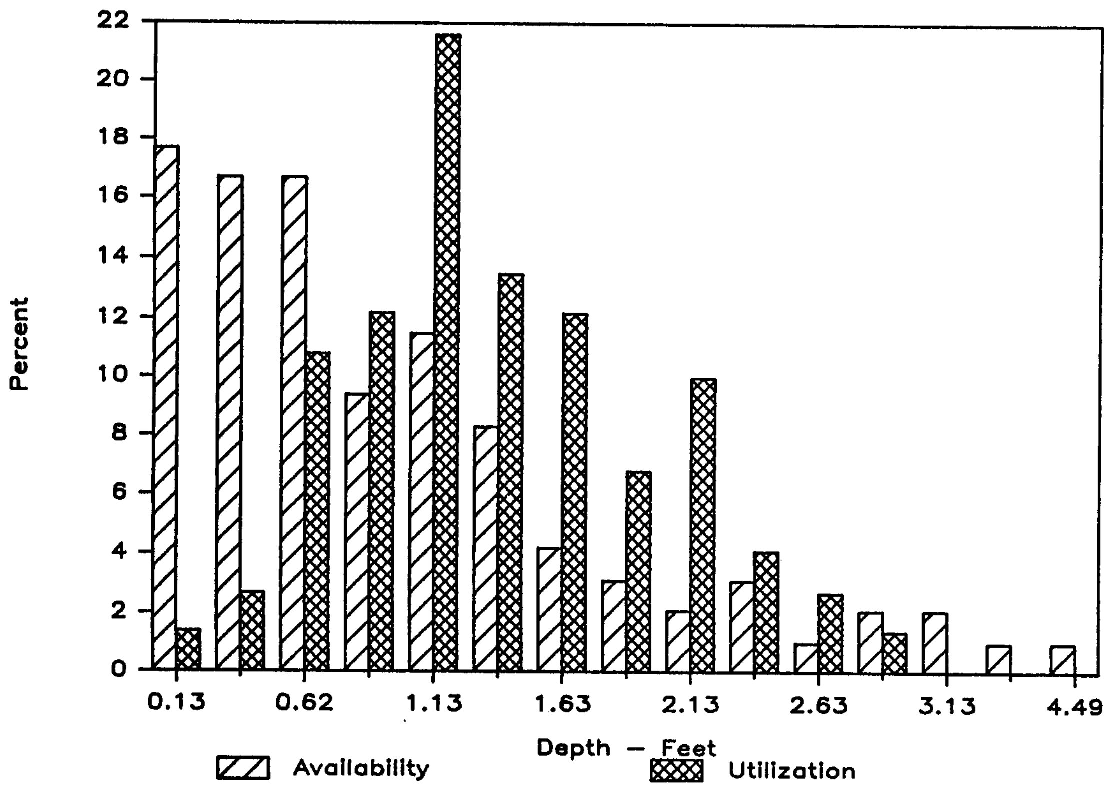

Figure 6. Depth utilization vs. availability for S. stimpsoni in the middle Nanue River, without repeats.

Table 3. Summary of substrate utilization and availability data for S. stimpsoni in three Hawaiian streams.

	Lower Hanawi			Wainiha			Middle Nanue		
Substratum	q	W/O	W/	q	W/O	W/	q	W/O	W/
10	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0
20	3.1	6.2	6.3	0.4	0.0	0.0	0.0	0.0	0.0
30	13.4	16.9	23.7	5.5	8.3	29.9	0.0	2.7	1.8
40	8.7	3.1	2.8	2.0	0.0	1.3	0.0	0.0	0.0
50	7.1	4.6	1.6	6.3	8.3	13.0	1.0	5.4	6.4
60	4.7	12.3	10.7	19.0	19.4	15.6	10.4	10.8	9.2
70	5.5	1.5	0.8	7.5	19.4	10.4	2.1	1.4	0.9
80	57.5	47.7	49.4	55.3	44.4	29.9	25.0	24.3	22.9
90	0.0	7.7	4.7	0.0	0.0	0.0	61.5	55.4	58.7
N	127	65	253	253	36	77	96	74	109

G test of independence Use versus Availability

	W/O	W/	W/O	W/	W/O	W/
G	15.9	36.3	14.1	26.5	5.8	7.1
significance	*	***	*	**	NS	NS

Substratum Categories:

10 = sand	0.2 in	50 = small cobble	2.9 - 5.9 in
20 = fine gravel	0.2 - 1.0 in	60 = medium cobble	5.9 - 8.9 in
30 = medium gravel	1.0 - 2.0 in	70 = large cobble	8.9 - 11.0 in
40 = coarse gravel	2.0 - 2.9 in	80 = boulder	11.0 in
		90 = bedrock	

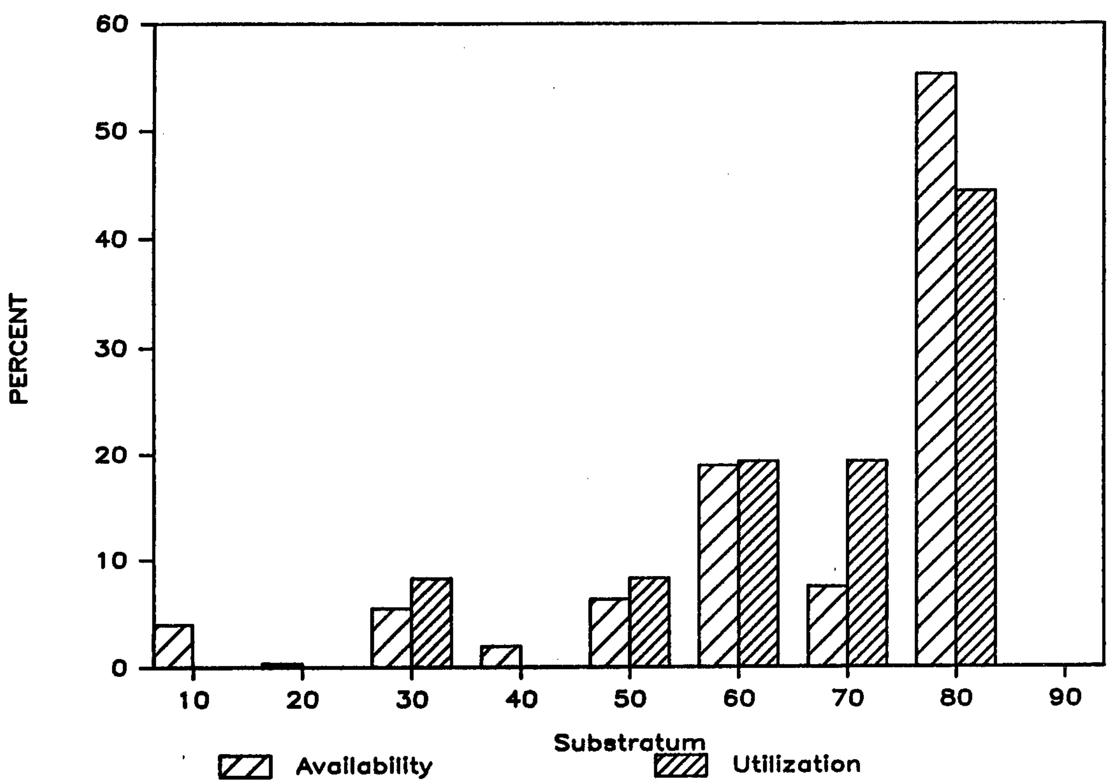

Figure 7. Substrate utilization vs. availability for S. stimpsoni in the Wainiha River, without repeats.

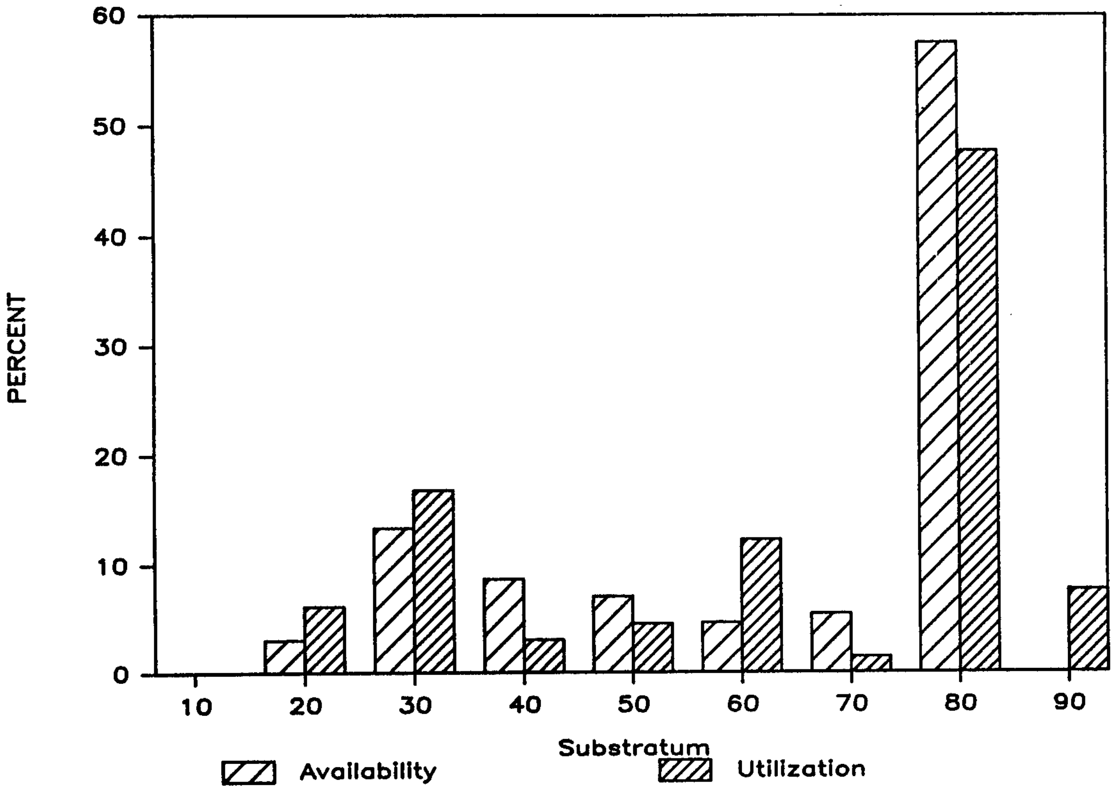

Figure 8. Substrate utilization vs. availability for S. stimpsoni in the lower Hanawi River, without repeats.

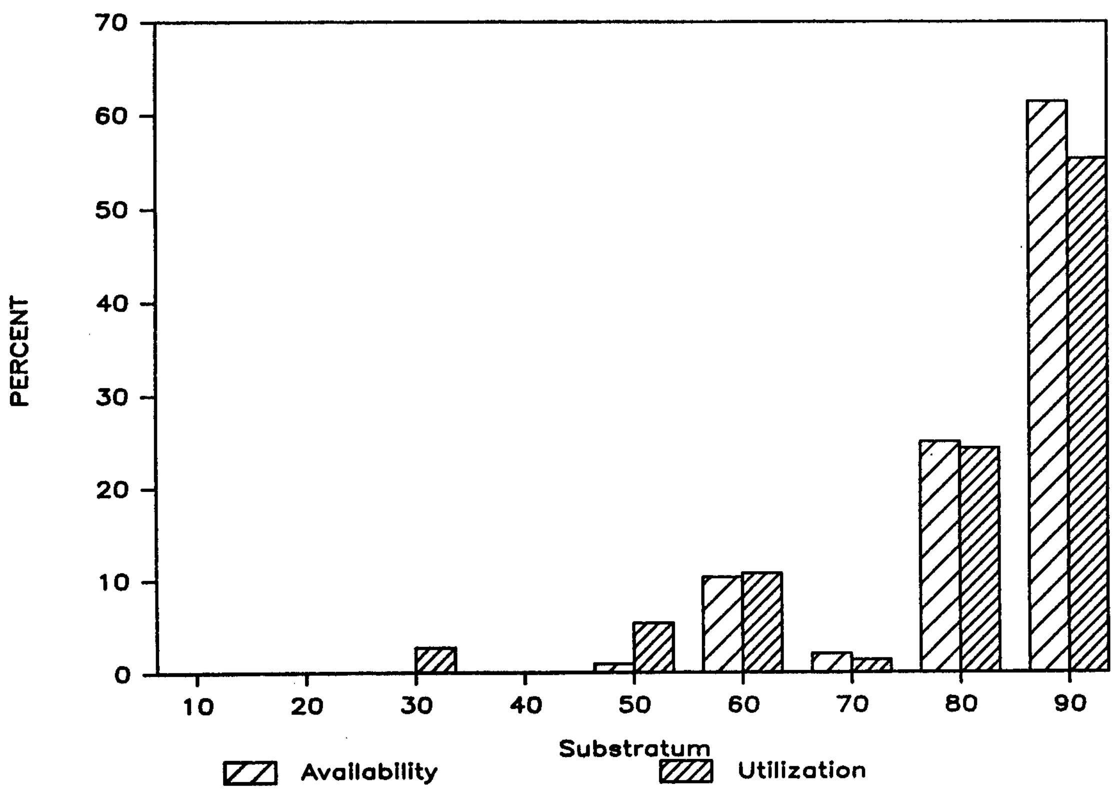

Figure 9. Substrate utilization vs. availability for S. stimpsoni in the middle Nanue River, without repeats.

Table 4. Summary of habitat type (regime) utilization and availability data for *S. stimpsoni* in three Hawaiian streams.

Regime	Lower Hanawi q	W/O	W	Wainiha q	W/O	W	Middle Nanue q	W/O	W
I (riffles)	36.0	56.3	48.8	24.9	36.1	54.5	17.9	50.0	16.7
P (pools)	25.6	10.9	10.7	2.4	0.0	0.0	25.3	13.5	30.4
R (runs)	38.4	32.8	40.5	72.7	63.9	45.5	56.8	36.5	52.9
N	125	64	252	253	36	77	95	74	102
G: Use versus Availability									
		W/O	W		W/O	W		W/O	W
G		9.2	14.3		2.0	22.8		1.0	0.6
significance		*	***		NS	***		NS	NS

Table 5. Summary of stream position utilization and availability data for *S. stimpsoni* in three Hawaiian streams.

Position	Lower Hanawi q	W/O	W	Wainiha q	W/O	W	Middle Nanue q	W/O	W
Center	40.2	63.1	62.8	36.4	30.6	27.3	50.0	50.0	51.4
Mid	29.9	23.1	24.9	36.4	52.8	64.9	19.8	13.5	11.0
Side	29.9	13.8	12.3	27.3	16.7	7.8	30.2	36.5	37.6
N	127	65	253	253	36	77	96	74	109
G: Use versus Availability									
		W/O	W		W/O	W		W/O	W
G		10.3	22.7		3.8	24.0		1.5	3.5
significance		*	***		NS	***		NS	NS

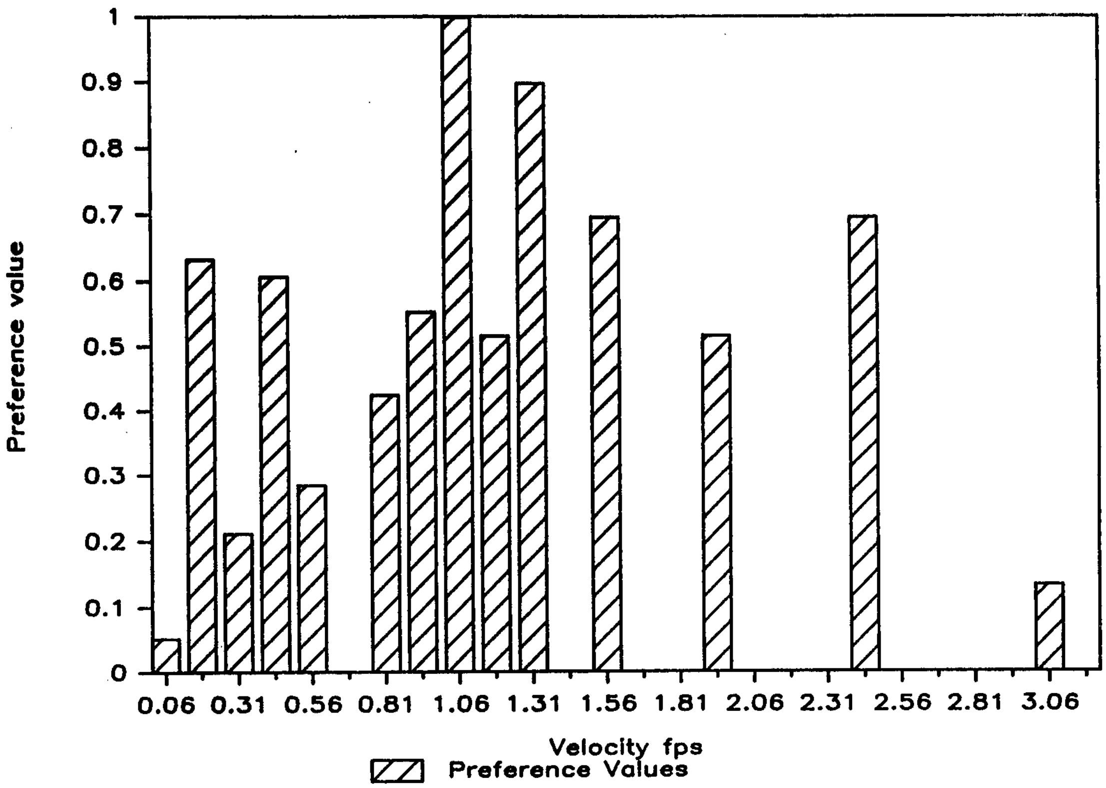

Figure 10. Velocity preference histogram for S. stimpsoni in lower Hanawi River.

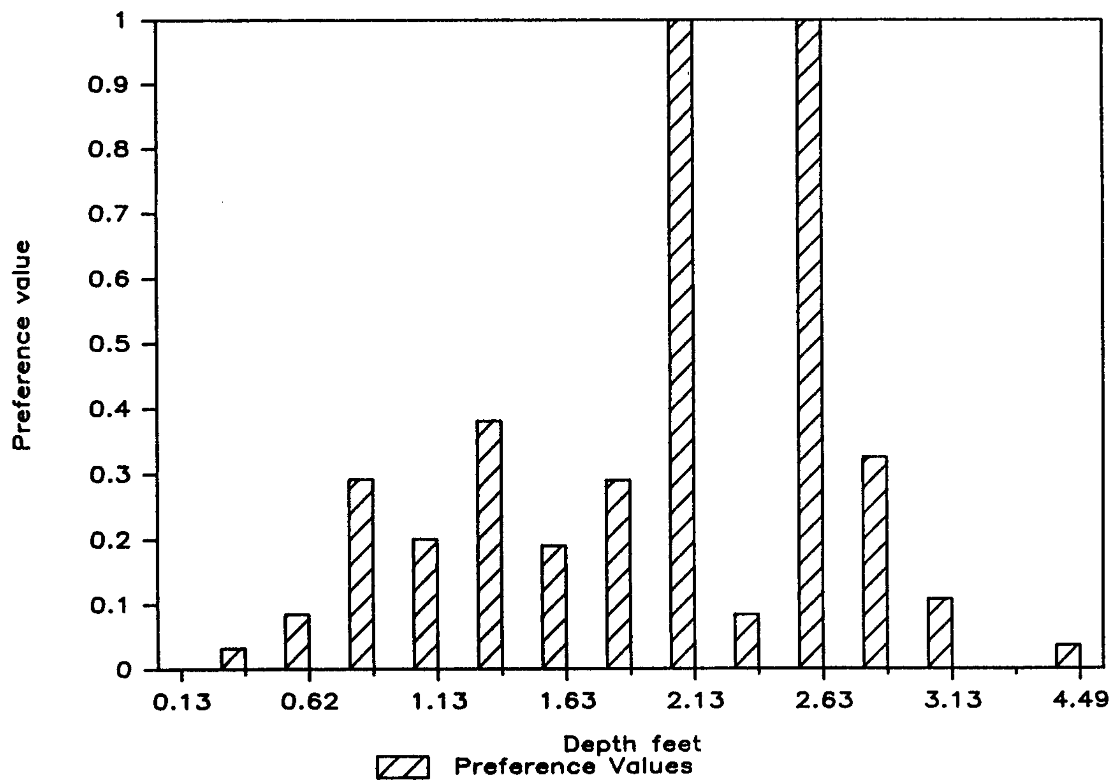

Figure 11. Depth preference histogram for S. stimpsoni in lower Hanawi River.

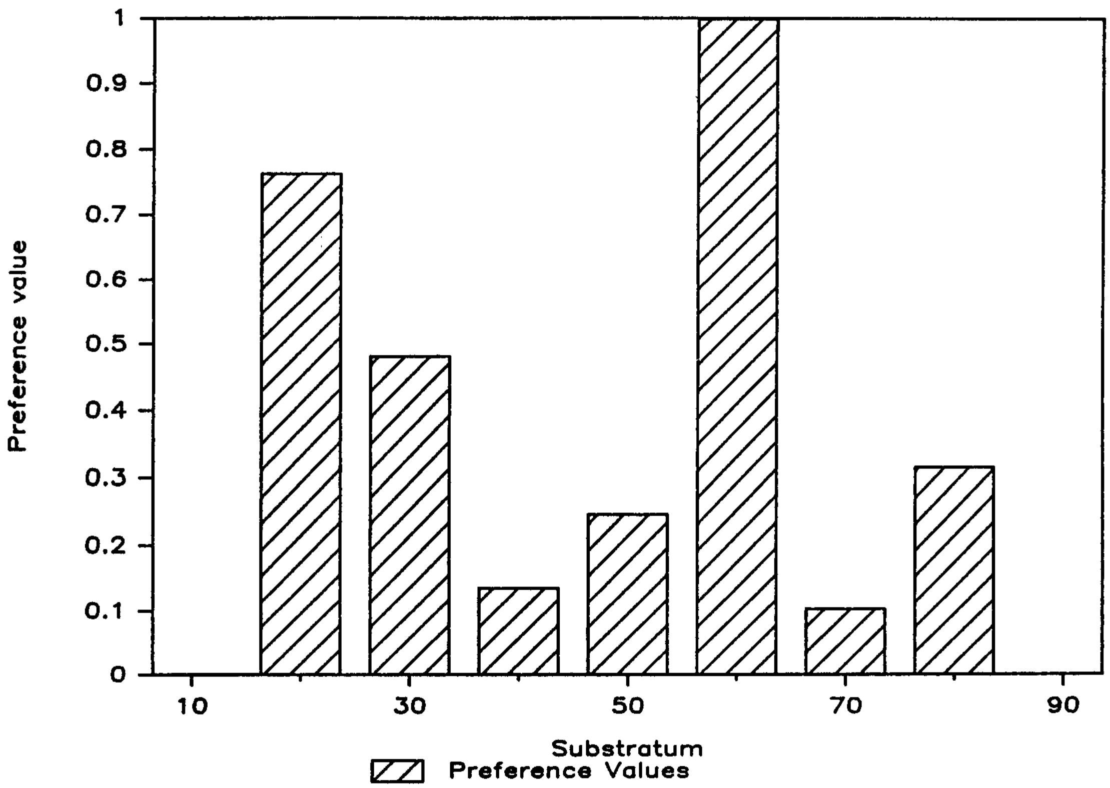

Figure 12. Substrate preference histogram for S. stimpsoni in lower Hanawi River.

particular locality be generalized in such a way that adjusted or transformed patterns can be compared statistically with a similarly normalized pattern from another habitat? In terms of the evaluation of the IFIM that we conducted, the question can be rephrased as: Can habitat utilization or preference curves for a species in a particular study reach be mathematically manipulated in such a way that they can be compared with curves from another study reach? If such normalized patterns for a particular species and life stage are not statistically different from each other, then normalized curves may be transferred from one stream to another. If there is no similarity in habitat utilization between streams, then there is no assurance that preference curves can be transferred.

Although no such statistical test has been reported in the ecological literature, an unpublished method has been developed to carry out such an evaluation (P.S. Petraitis, University of Pennsylvania, 1986; pers. comm.). Because this method has not appeared in the literature, it will be necessary to outline its development and rationale.

This method is based, like habitat preference curves, on electivities. For two sites that are to be compared, electivity functions are first calculated. It might, at first, be thought that a simple comparison of the electivities in the two sites could be compared using goodness-of-fit statistics. This is not possible, since the electivity function for each study site is correlated with the microhabitat availability at that site. The

denominator used in calculating electivity is the habitat availability. This problem can be alleviated by combining the electivity from the second study site with the habitat availability in the first site. As an example, consider two sites, j and k. In each of these sites, the habitat parameter can be divided into n states from 1 to n, with each state represented by i. With this notation, the utilization by the organism in habitat j of the resource or habitat parameter i can be represented by Q_{ji}. The electivity for resource i in habitat j is then

$$E_{ji} = P_{ji} / Q_{ji} \tag{1}$$

In a similar manner, the utilization for resource i at site k is P_{ki}, the availability is Q_{ki}, and the electivity is

$$E_{ki} = P_{ki} / Q_{ki} \tag{2}$$

Now it can be seen why a simple comparison of E_{ji} with E_{ki} cannot be made, because of the correlation of the electivity functions in a particular site with the availability of the microhabitat levels at that site. However, if the null hypothesis is that the fish have an intrinsic preference, which cannot be directly assessed from utilization functions because of the influence of the availability of resources on the observed utilization patterns, then this null hypothesis can be tested by generating a predicted P and then comparing this with observed utilization patterns. The predicted utilization pattern is calculated by multiplying the electivity at site k by the availability at site j resulting in a predicted utilization pattern.

$$\hat{P}_{ji} = E_{ki} * Q_{ji} \tag{3}$$

The predicted utilizations for each level of the habitat parameter can then be compared with the actual observed utilization at that site. If no difference is apparent between predicted and observed utilizations, then the fish distribution from the second site can be thought of as predicting the distribution of fish at the first site. In statistical terms, we can say that the null hypothesis of no difference between the study sites cannot be rejected.

We encountered two problems with applying this technique with our data set. The first stems from asymmetrical results. If the electivity at site j predicts the utilization at site k, while the electivity from site k does not yield a good fit of predicted utilization at site j, a problem in interpretation results. At the present time, no simple remedy is available for this difficulty. As will be discussed below, this problem could result from sample sizes that are too small in one or both of the study sites, differential effects of schooling in the two sites, lack of similarity between the flow conditions in the two streams at the time the data were obtained, or differences in the streams themselves.

The second problem stems from data with ragged frequency polygons and unrealistic electivity curves due to utilization of rare habitat categories. If the electivities are not a good representation of the actual relationship between utilization and availability in the stream, use of these flawed data can only result in flawed conclusions. In our data sets, the most troublesome problem was with habitat availability estimates that were either zero or very low, yielding undefined or unrealistically high electivity values.

Two solutions were possible. The first was to group categories even further than they were for the utilization vs. availability studies and then to treat these broad parameter ranges as categorical variables. The second was to fit curves to the observed data and to carry out the operation on these mathematically smoothed data. We will present results of such comparisons carried out on our data grouped into quite broad intervals, and values derived from functions resulting from fitting empirical curves to the data. Empirical curve-fitting was carried out on velocity and depth only, as we consider substratum, regime, and position to be categorical variables.

We required that as few as possible of the data sets had null categories, i.e., zero values for availability or utilization for any value. Substratum was grouped into three and sometimes only two levels. Velocity was grouped into six or sometimes five unequal intervals. Depth was grouped into four and sometimes three unequal intervals. Expected utilization values were calculated as described above and compared with the observed utilization value.

For the second method, we only analyzed the continuous variables of velocity and depth. For these two variables, a smoothed function was drawn through observed frequency data for fish habitat utilization and habitat availability, and then the comparisons of the generated expected utilization vs. the observed utilizations could be tested against each other.

The first step in this procedure was to fit an empirical curve to the data. To allow comparison between data sets, the function had to be of the same form for all comparisons. The curves used for velocity were

$$\text{Frequency} = A * e^{B*\text{Velocity}} + C * \text{Velocity} * e^{B*\text{Velocity}} \tag{4}$$

This curve for frequency of observations at each velocity had three fitted parameters. The curves for depth utilization were of the form

$$\text{Frequency} = C * \text{Depth} * e^{B*\text{Depth}} \tag{5}$$

The simpler curve for frequency of observations at each depth results from our belief that the depth utilization curve could be forced to pass through zero, but that this was unrealistic for velocity, i.e., a fish could have a positive utilization for zero velocity, but could not have a possible utilization for zero depth. Data for depth availability were fitted to the three-parameter curve, since zero depths did occur. The depth availability data for Wainiha were fitted to the two-parameter equation, since use of the

three-parameter equation resulted in negative availability values for shallow depths. These fitted curves are presented in Figures 13 through 18.

The next step was to generate an electivity curve using these functions for each utilization and availability pair. Finally, the electivities from one study site were multiplied by the habitat availabilities at a second site and then normalized generated predicted utilizations at the first site which could then be compared with the observed utilization at that site. These comparisons are shown in Figures 19 through 21. Since we were comparing two continuous functions, one observed and one expected (the latter derived from the availability at the first stream), we compared the curves using the Kolmogorov-Smirnov test. Because these empirically fitted curves were continuous, there was potentially an infinite number of points. Use of all these points for the tests would give an unrealistically large sample size. To make our tests conservative, we chose points along the curves corresponding to velocity and depth categories where we had actually obtained data. Thus, sample size was adjusted to correspond to actual field data.

RESULTS OF TESTS OF TRANSFERABILITY OF PREFERENCE CURVES

Data are presented by stream in Tables 6 through 12, with the observed utilization shown next to the utilization predicted from the other named stream. The significance of the difference between the two columns is determined by Chi-square analysis. A significant difference indicates that the utilization determined from the electivity in the second stream fails to predict correctly the observed utilization in the first stream, that is, the utilization functions are not transferable. It is also of interest to see whether the predictions are reciprocal, that is, if the data from stream A correctly predicts the utilization for stream b, i.e., is the reverse true? Cases with reciprocal significant differences indicate both utilization functions are different from each other and clearly not transferable.

When observed utilization data without repeat observations from Wainiha are compared with the predictions from lower Hanawi (Table 6), only position in the stream is significantly different, with more fish occurring in the sides and marginal parts of the stream than would be predicted. Comparisons between these two streams are not strongly symmetrical, since predictions for Wainiha from lower Hanawi for velocity and depth utilization for S. stimpsoni are not significantly different from observed utilization, while predictions for lower Hanawi from Wainiha depth, velocity, and position (Table 8) are significantly different from what was observed there. When data from all individuals in schools were included in the analyses, very strong and reciprocal differences were apparent for all microhabitat parameters.

When observed utilization patterns in Wainiha are compared with utilizations predicted from middle Nanue (Table 7), depth and position are significantly different for the data sets without repeat observations. These differences are symmetrical since the observed utilization patterns in middle Nanue (Table 10) differ from those predicted from Wainiha in the same two

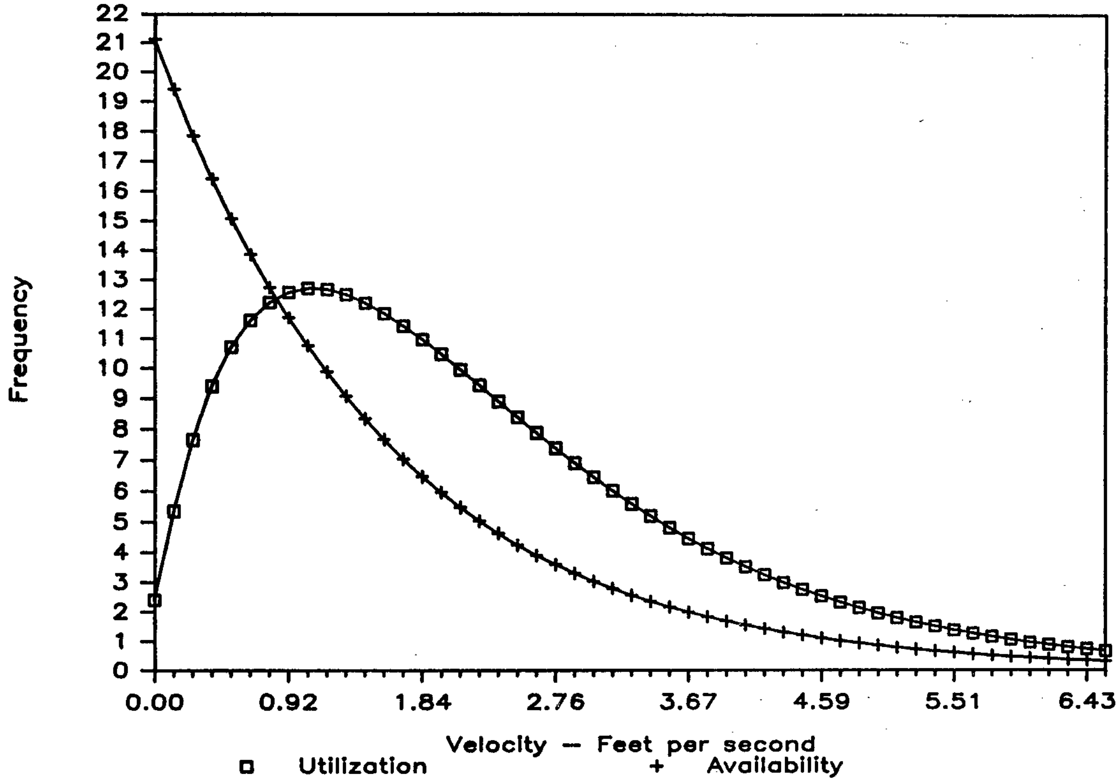

Figure 13. Velocity utilization and availability curves for <u>S. stimpsoni</u> in the lower Hanawi River.

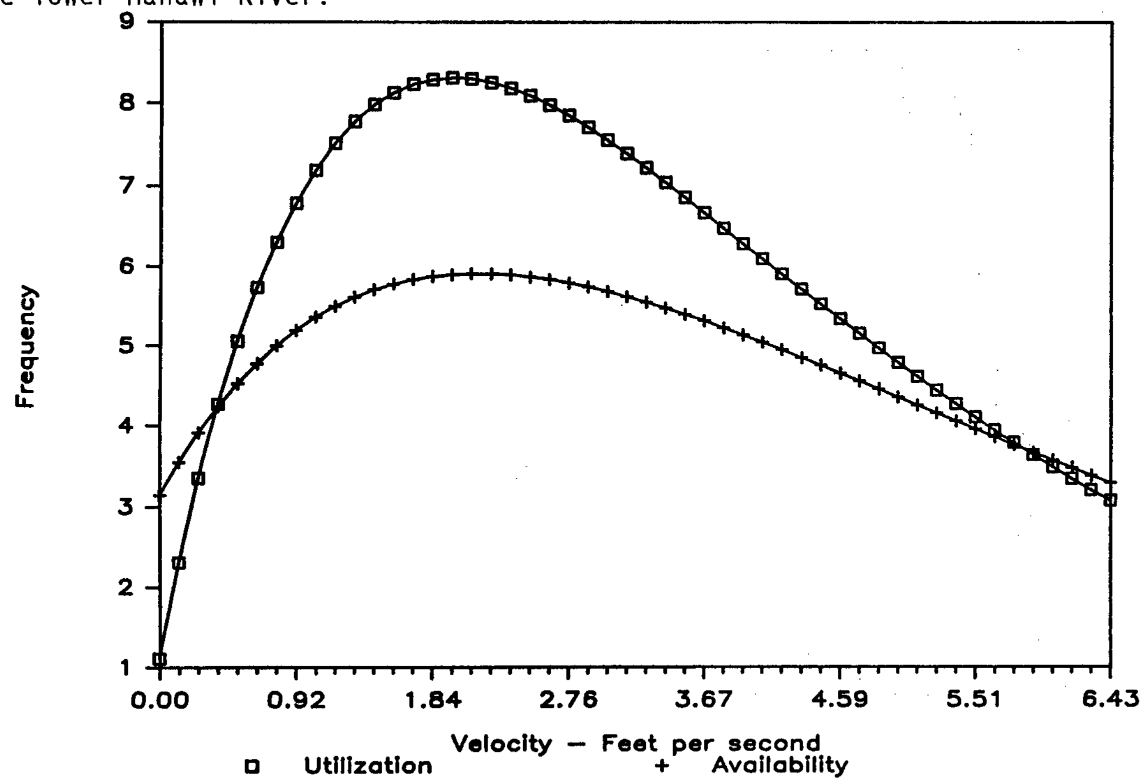

Figure 14. Velocity utilization and availability curves for <u>S. stimpsoni</u> in the Wainiha River.

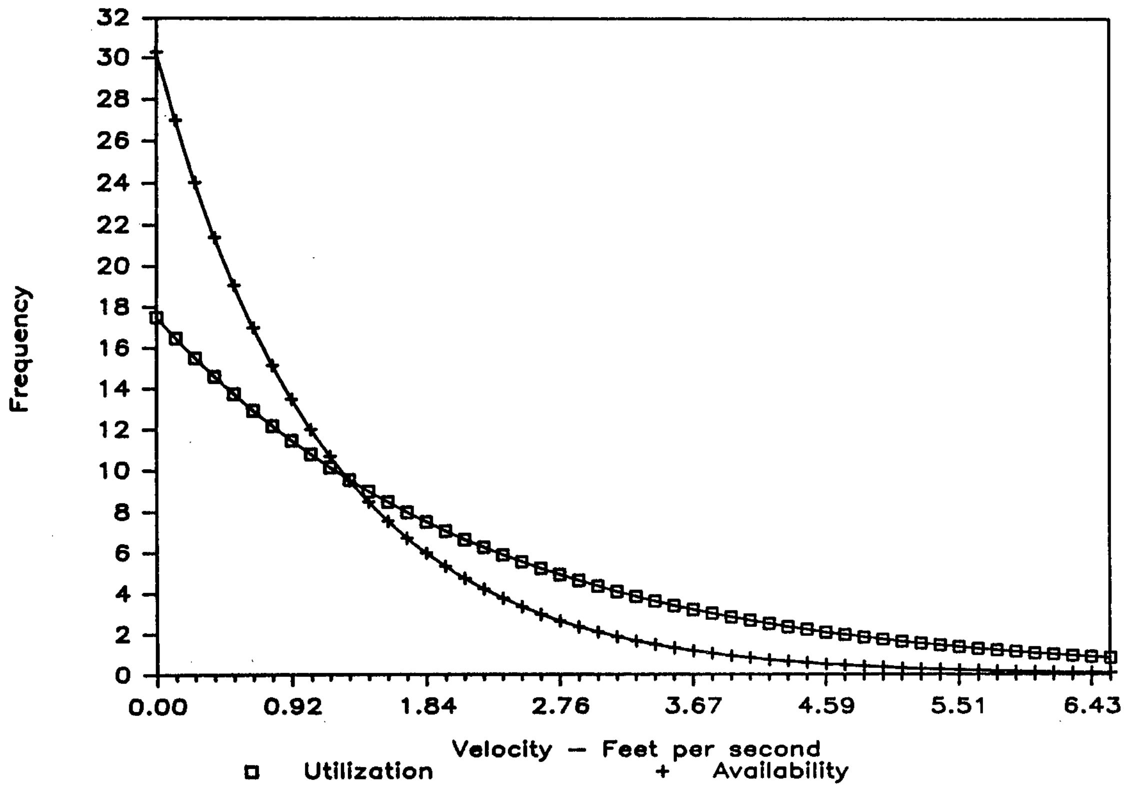

Figure 15. Velocity utilization and availability curves for S. stimpsoni in the middle Nanue River.

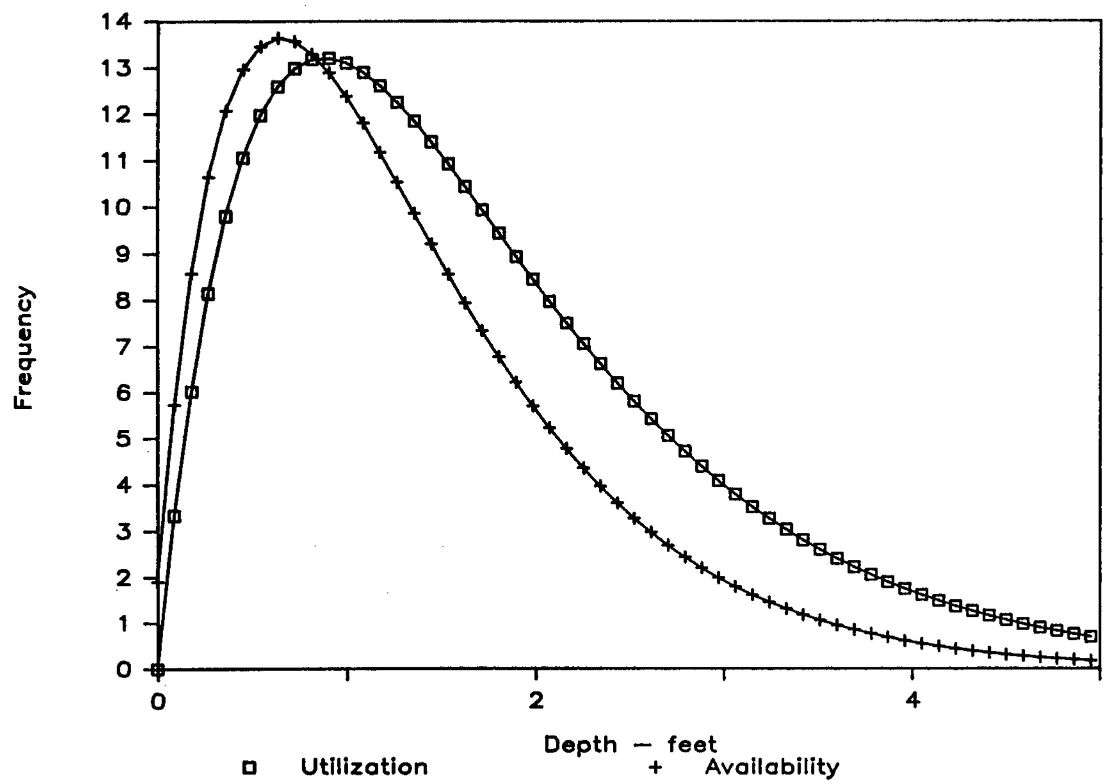

Figure 16. Depth utilization and availability curves for S. stimpsoni in the lower Hanawi River.

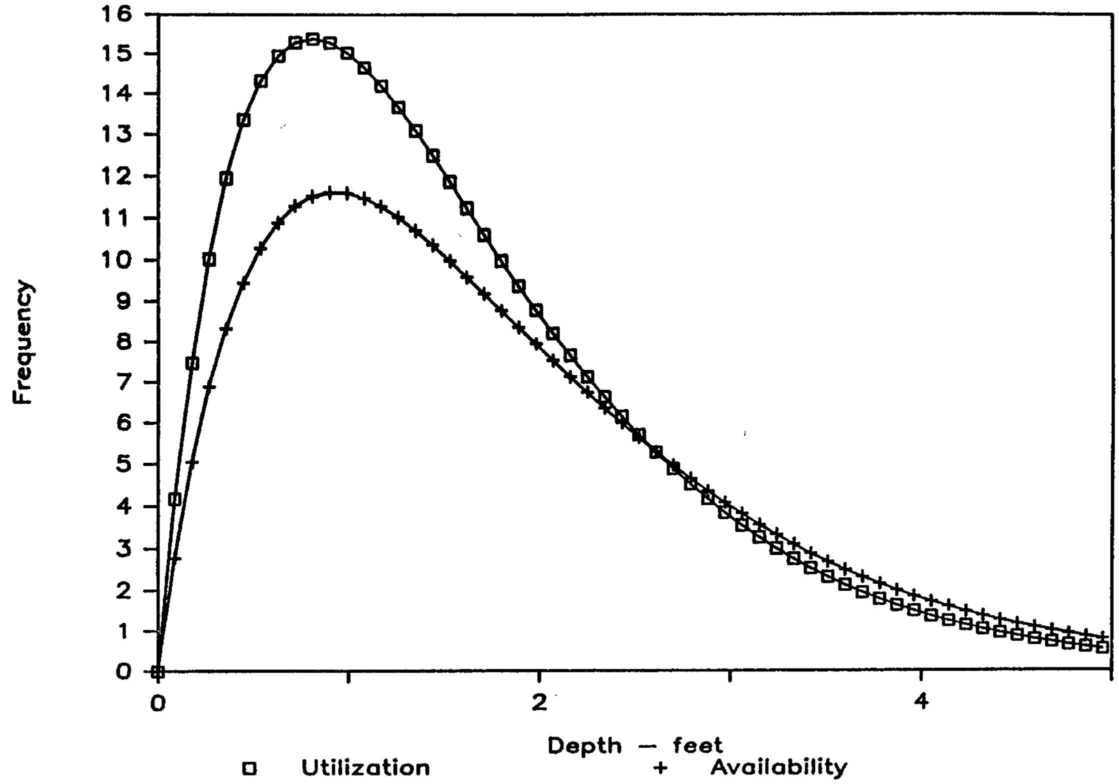

Figure 17. Depth utilization and availability curves for S. stimpsoni in the Wainiha River.

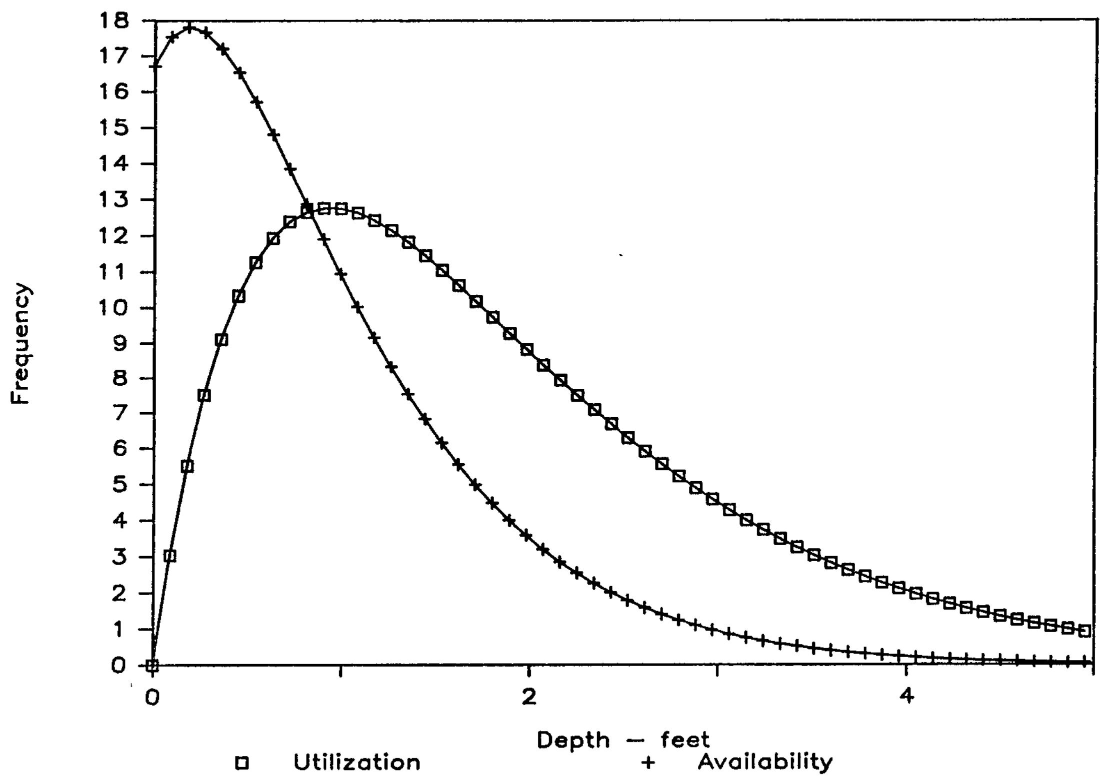

Figure 18. Depth utilization and availability curves for S. stimpsoni in the lower middle Nanue River.

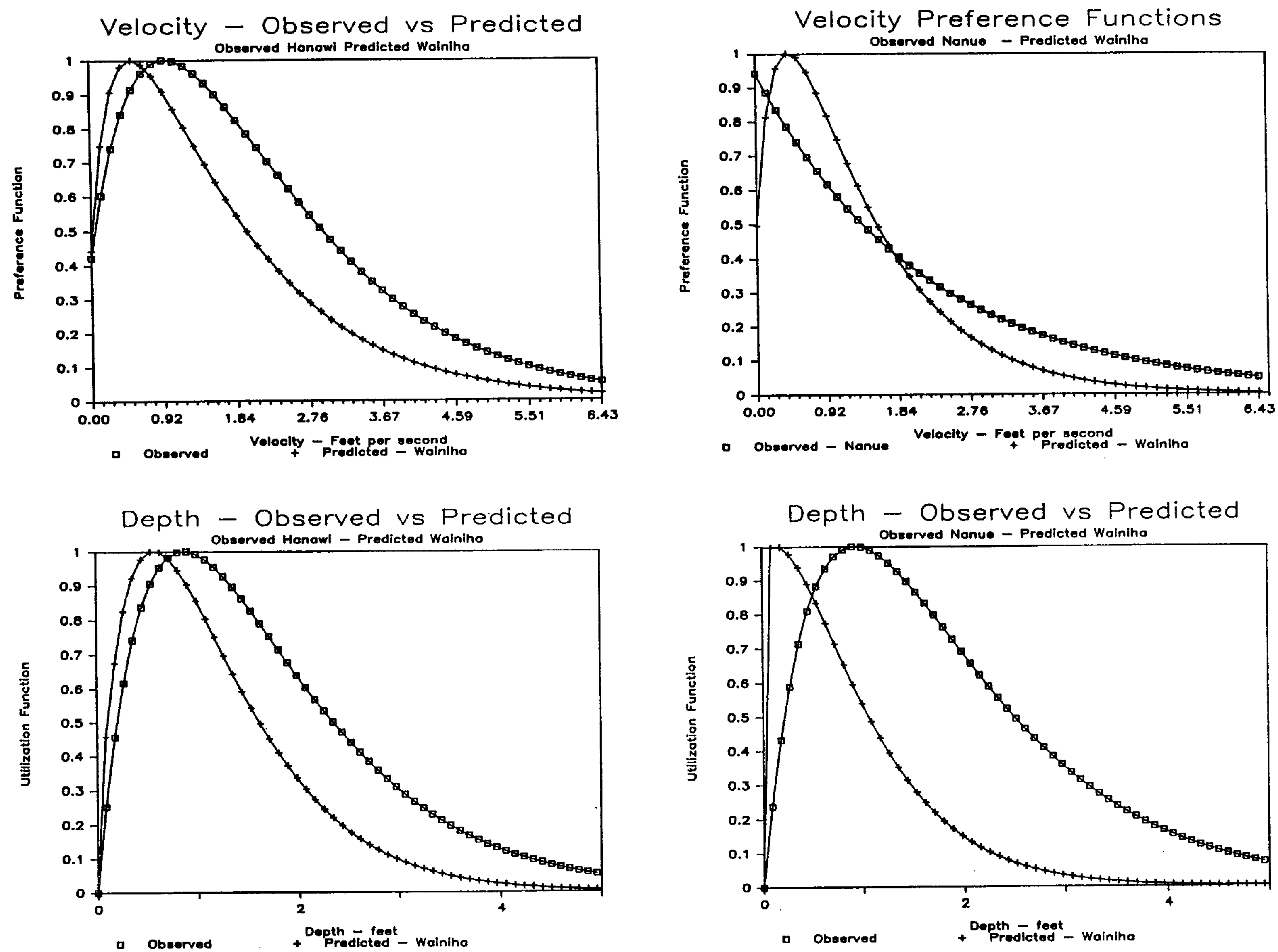

Figure 19. Comparison of observed velocity and depth utilization by S. stimpsoni in Hanawi and Nanue Rivers, with utilization predicted from preference functions derived in the Wainiha River.

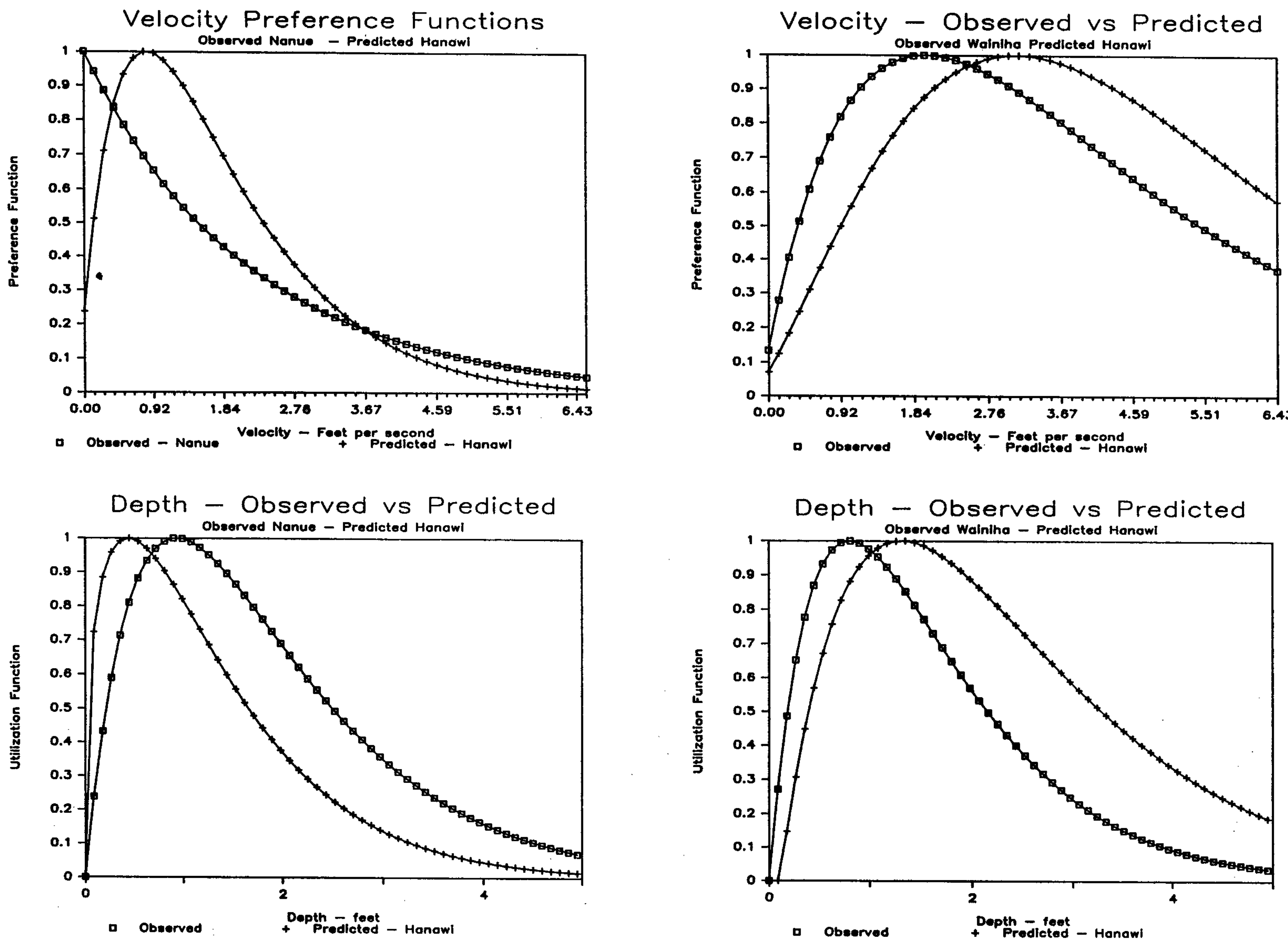

Figure 20. Comparison of observed velocity and depth utilization by S. stimpsoni in Nanue and Wainiha Rivers, with utilization predicted from preference functions derived in the Hanawi River.

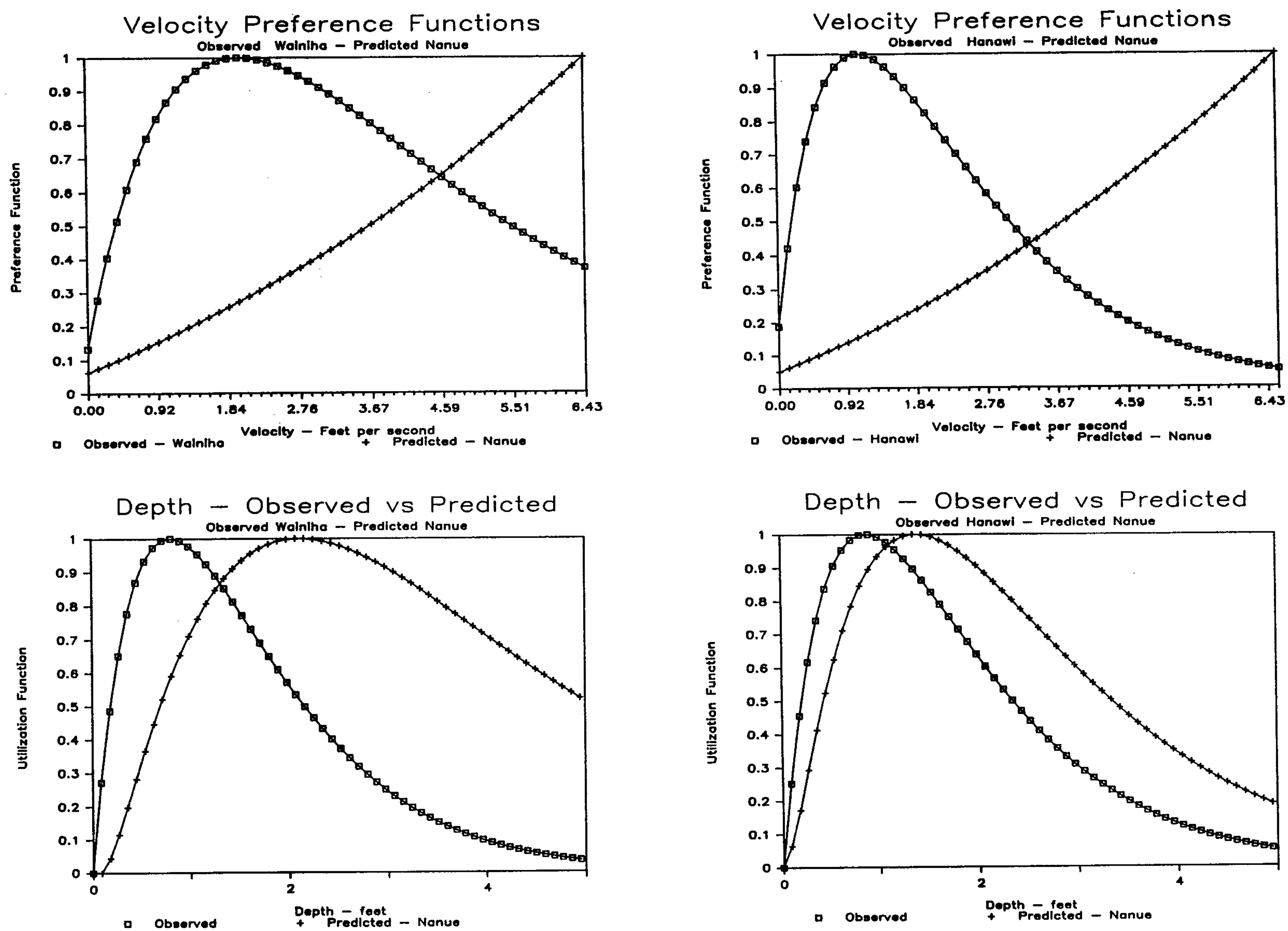

Figure 21. Comparison of observed velocity and depth utilization by S. stimpsoni in Wainiha and Hanawi Rivers, with utilization predicted from preference functions derived in the Nanue River.

Table 6. Chi square tests of observed microhabitat utilization in Wainiha River vs. predicted utilization from lower Hanawi River.

	Without repeats N = 36		With repeats N = 77	
SUBSTRATUM CATEGORY	Observed	Expected	Observed	Expected
Sand and gravel	3.00	4.43	24.00	12.94
Cobbles	17.00	13.46	30.00	20.71
Boulders and bedrock	16.00	19.08	23.00	43.35
SIGNIFICANCE	$p > 0.05$		$p > 0.001$	
VELOCITY				
0.000 - 0.437	1.00	2.59	1.00	8.09
0.438 - 0.812	5.00	3.71	27.00	10.16
0.813 - 1.187	10.00	6.48	15.00	17.40
1.188 - 1.687	9.00	8.53	15.00	16.09
1.688 - 2.937	9.00	12.74	16.00	21.64
2.938	2.00	1.94	3.00	3.62
SIGNIFICANCE	$p > 0.05$		$p < 0.001$	
DEPTH				
0.000 - 1.124	3.00	1.58	3.00	3.62
1.125 - 1.874	19.00	16.20	55.00	27.95
1.875 - 2.874	11.00	15.66	16.00	38.42
2.875	3.00	2.56	3.00	7.01
SIGNIFICANCE	$p > 0.05$		$p < 0.001$	
POSITION				
Center	11.00	21.02	21.00	44.51
Margin	19.00	10.33	50.00	23.72
Side	6.00	4.64	6.00	8.87
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
REGIME				
Riffles	13.00	13.75	42.00	23.33
Pools	0.00	0.36	0.00	0.69
Runs	23.00	21.89	35.00	52.98
SIGNIFICANCE	$p > 0.05$		$p < 0.001$	

habitat parmeters. Additionally, the observed use of regime by single *S. stimpsoni* is different from the expected utilization predicted from Wainiha River. When the effect of schooling is taken into account, velocity and regime also show significant differences in comparisons between the observed utilization in Wainiha and those predicted from electivities from middle Nanue (Table 7). The differences in the data for schooling fishes are not symmetrical for velocity.

The last set of comparisons is between middle Nanue Stream and lower Hanawi (Tables 9 through 11). Data without repeat observations show that significant differences are apparent between predicted and observed habitat utilization patterns for all parameters except substratum, and that these differences are symmetrical.

Table 7. Chi square tests of observed microhabitat utilization in Wainiha River vs. predicted utilization from middle Nanue River.

	Without repeats N = 36		With repeats N = 77	
SUBSTRATUM CATEGORY*	Observed	Expected	Observed	Expected
Sand, gravel, and cobbles	20.00	20.48	54.00	41.35
Boulders and bedrock	16.00	15.52	23.00	35.65
SIGNIFICANCE	$p > 0.05$		$p > 0.05$	
VELOCITY				
0.000 - 0.437	1.00	2.56	1.00	6.31
0.438 - 0.812	5.00	3.13	27.00	7.24
0.813 - 1.187	10.00	5.87	15.00	14.32
1.188 - 1.687	9.00	7.49	15.00	15.94
1.688 - 2.937	9.00	14.80	16.00	29.80
2.938	2.00	2.20	3.00	3.39
SIGNIFICANCE	$p > 0.05$		$p < 0.001$	
DEPTH				
0.000 - 1.124	3.00	1.12	3.00	1.93
1.125 - 1.874	19.00	11.99	55.00	29.41
1.875 - 2.874	11.00	21.67	16.00	43.97
2.875	3.00	1.22	3.00	1.69
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
POSITION				
Center	11.00	13.90	21.00	31.42
Margin	19.00	9.47	50.00	17.02
Side	6.00	12.60	6.00	28.57
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
REGIME				
Riffles	13.00	13.90	42.00	19.10
Pools	0.00	1.01	0.00	2.39
Runs	23.00	21.10	35.00	55.59
SIGNIFICANCE	$p < 0.05$		$p < 0.001$	

* Due to empty cells substratum was divided into only two categories.

When the distribution of schooling fishes is taken into account, the only change is that the difference between observed velocity utilization for middle Nanue and predicted is no longer significant, and observed substratum use in middle Nanue is significantly different from that predicted from lower Hanawi (Table 11).

It appears that major differences between study reaches preclude the successful transfer of utilization functions from one stream to another.

These comparisons, using observations grouped into broad categories, do not support the conclusion that any generalized fish habitat utilization curves have been devised. Comparisons between large streams (lower Hanawi and Wainiha) and small streams (middle Nanue) suggest that differences between the

Table 8. Chi square tests of observed microhabitat utilization in lower Hanawi River vs. predicted utilization from Wainiha River.

	Without repeats N = 65		With repeats N = 253	
SUBSTRATUM CATEGORY	Observed	Expected	Observed	Expected
Sand and gravel	17.03	15.08	82.98	141.93
Cobbles	11.96	10.34	33.14	44.28
Boulders and bedrock	36.01	39.59	136.87	66.79
SIGNIFICANCE	$p > 0.05$		$p < 0.001$	
VELOCITY				
0.000 - 0.437	20.00	10.01	94.00	11.64
0.438 - 0.812	14.00	28.41	58.00	155.34
0.813 - 1.187	12.00	7.74	49.00	42.50
1.188 - 1.687	7.00	4.23	20.00	18.72
1.688 - 2.937	7.00	8.00	18.00	13.41
2.938	5.00	6.63	14.00	11.39
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
DEPTH				
0.000 - 1.124	6.00	10.27	26.00	18.72
1.125 - 1.874	34.00	36.27	110.00	190.76
1.875 - 2.874	19.00	12.09	87.00	31.88
2.875	6.00	6.37	30.00	11.39
SIGNIFICANCE	$0.05 > p > 0.001$		$p < 0.001$	
POSITION				
Center	41.00	23.01	159.00	82.98
Margin	15.00	29.51	63.00	146.49
Side	9.00	12.48	31.00	23.53
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
REGIME*				
Riffles	36.00	39.46	124.00	193.80
Pools	7.00	0.00	27.00	0.00
Runs	21.00	25.55	102.00	59.20
SIGNIFICANCE	$p > 0.05$		$p < 0.001$	

* Because of the expected values of 0.0 a Kolmogorov-Smirnov test was used.

sites where data are collected may be of such a nature as to preclude the simple formulation of generalized fish utilization curves.

USE OF EMPIRICAL CURVES FOR VELOCITY AND DEPTH

The empirical curves that were fitted to the continuous variables, velocity and depth, were also compared to test for transferability of these smoothed data between streams (Table 12). Comparisons of depth and velocity utilization based on the empirical curves suggest less difference between Hanawi and Wainiha than for comparisons involving middle Nanue. This could be

Table 9. Chi square tests of observed microhabitat utilization in lower Hanawi River vs. predicted utilization from middle Nanue River.

	Without repeats N = 65		With repeats N = 253	
SUBSTRATUM CATEGORY*	Observed	Expected	Observed	Expected
Sand, gravel, and cobbles	30.00	35.56	116.00	130.30
Boulders and bedrock	36.00	29.45	137.00	122.71
SIGNIFICANCE	$p > 0.05$		$p > 0.05$	
VELOCITY				
0.000 - 0.437	20.00	26.78	94.00	87.79
0.438 - 0.812	14.00	20.22	58.00	49.34
0.813 - 1.187	12.00	5.92	49.00	47.56
1.188 - 1.687	7.00	2.28	20.00	23.53
1.688 - 2.937	7.00	2.15	18.00	29.35
2.938	5.00	7.67	14.00	15.43
SIGNIFICANCE	$p \leq 0.001$		$p > 0.05$	
DEPTH				
0.000 - 1.124	6.00	4.68	26.00	14.42
1.125 - 1.874	34.00	28.02	110.00	123.97
1.875 - 2.874	19.00	29.12	87.00	106.51
2.875	6.00	3.19	30.00	8.10
SIGNIFICANCE	$0.05 > p > 0.01$		$p < 0.001$	
POSITION				
Center	41.00	27.04	159.00	109.80
Margin	15.00	13.72	63.00	44.28
Side	9.00	24.31	31.00	98.92
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
REGIME				
Riffles	37.00	31.20	124.00	84.76
Pools	7.00	16.51	27.00	77.67
Runs	21.00	17.29	102.00	90.32
SIGNIFICANCE	$0.01 > p > 0.001$		$p < 0.001$	

* Due to empty cells substratum was divided into only two categories.

due to the fact that middle Nanue is a much smaller stream than the other two, or because S. stimpsoni is the only species common in middle Nanue, whereas it co-occurs with large numbers of Awaous stamineus in Wainiha and lower Hanawi.

Table 10. Chi square tests of observed microhabitat utilization in middle Nanue River vs. predicted utilization from Wainiha River.

	Without repeats N = 74		With repeats N = 109	
SUBSTRATUM CATEGORY*	Observed	Expected	Observed	Expected
Sand, gravel, and cobbles	15.00	16.13	20.00	27.90
Boulders and bedrock	59.00	57.87	89.00	81.10
SIGNIFICANCE	$p > 0.05$		$p > 0.05$	
VELOCITY				
0.000 - 0.437	33.00	32.04	52.00	54.50
0.438 - 0.812	13.00	14.65	19.00	22.02
0.813 - 1.187	11.00	11.62	17.00	17.00
1.188 - 1.687	6.00	6.51	8.00	6.65
1.688 - 2.937	7.00	5.77	9.00	5.34
2.938	4.00	3.48	4.00	3.49
SIGNIFICANCE	$p > 0.05$		$p > 0.05$	
DEPTH				
0.000 - 1.124	11.00	13.25	13.00	21.91
1.125 - 1.874	35.00	40.26	59.00	49.81
1.875 - 2.874	25.00	15.10	34.00	26.60
2.875	3.00	5.40	3.00	10.57
SIGNIFICANCE	$0.05 > p > 0.01$		$0.01 > p > 0.001$	
POSITION				
Center	37.00	53.95	56.00	79.57
Margin	10.00	10.51	12.00	16.79
Side	27.00	9.55	41.00	12.64
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
REGIME#				
Riffles	20.00	25.31	24.00	57.12
Pools	21.00	0.00	31.00	0.00
Runs	33.00	48.69	54.00	51.88
SIGNIFICANCE	$0.05 > p > 0.01$		$p < 0.001$	

* Due to empty cells substratum was divided into only two categories.

Because of the expected values of 0.0 a Kolmogorof-Smirnov test was used.

Even with the conservative nature of these tests, using as we did only the actual number of velocity and depth categories in the original data set and the greatly simplified form of the empirically smoothed curves, the majority of the comparisons between observed and predicted utilizations were significantly different. This result reinforces the conclusion from the tests using grouped data that the fish utilization curves we produced are not transferable from one stream to another. This conclusion does not prove that more generalized utilization or preference curves cannot be produced. Our results strongly indicate, however, that effort put into obtaining this sort of information may not be worth the returns when compared with costs of determining fish habitat curves on a case by case basis for proposed projects.

Table 11. Chi square tests of observed microhabitat utilization in middle Nanue River vs. predicted utilization from lower Hanawi River.

	Without repeats N = 74		With repeats N = 109	
SUBSTRATUM CATEGORY*	Observed	Expected	Observed	Expected
Sand, gravel, and cobbles	15.00	10.88	20.00	12.21
Boulders and bedrock	59.00	63.12	89.00	96.79
SIGNIFICANCE	$p > 0.05$		$0.05 > p > 0.01$	
VELOCITY				
0.000 - 0.437	33.00	14.28	52.00	7.96
0.438 - 0.812	13.00	22.64	19.00	68.56
0.813 - 1.187	11.00	20.50	17.00	17.22
1.188 - 1.687	6.00	7.84	8.00	7.30
1.688 - 2.937	7.00	4.66	9.00	4.69
2.938	4.00	4.07	4.00	3.27
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
DEPTH				
0.000 - 1.124	11.00	20.79	13.00	14.93
1.125 - 1.874	35.00	39.15	59.00	81.10
1.875 - 2.874	25.00	8.81	34.00	9.16
2.875	3.00	5.25	3.00	3.71
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
POSITION				
Center	37.00	34.85	56.00	50.25
Margin	10.00	23.83	12.00	47.31
Side	27.00	15.32	41.00	11.55
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	
REGIME				
Riffles	20.00	23.75	24.00	27.90
Pools	21.00	9.10	31.00	12.21
Runs	33.00	41.14	54.00	68.69
SIGNIFICANCE	$p < 0.001$		$p < 0.001$	

* Due to empty cells substratum was divided into only two categories.

Table 12. Results of comparison of fitted curves from observed vs. expected values.

The value entered in the table is the 'D' statistic from the Kolmogorov-Smirnov nonparametric test
* = $p < 0.05$ ** = $p < 0.01$

	Observed - Lower Hanawi, Expected - Wainiha: Without repeats N = 65	Observed - Lower Hanawi, Expected - Wainiha: With repeats N = 253	Observed - Lower Hanawi, Expected - Middle Nanue: Without repeats N = 65	Observed - Lower Hanawi, Expected - Middle Nanue: With repeats N = 253
VELOCITY	0.120 NS	#	0.207 **	0.410 **
DEPTH	0.034 NS	0.231 *	0.308 **	0.188 **

	Observed - Wainiha, Expected - Lower Hanawi: Without repeats N = 36	Observed - Wainiha, Expected - Lower Hanawi: With repeats N = 77	Observed - Wainiha, Expected - Middle Nanue: Without repeats N = 36	Observed - Wainiha, Expected - Middle Nanue: With repeats N = 77
VELOCITY	0.037 NS	#	0.493 **	#
DEPTH	0.034 NS	0.249 *	0.342 **	0.377 *

	Observed - Middle Nanue, Expected - Lower Hanawi: Without repeats N = 74	Observed - Middle Nanue, Expected - Lower Hanawi: With repeats N = 109	Observed - Middle Nanue, Expected - Wainiha: Without repeats N = 74	Observed - Middle Nanue, Expected - Wainiha: With repeats N = 109
VELOCITY	0.094 NS	0.260 **	0.211 NS	#
DEPTH	0.490 **	0.143 NS	0.515 **	0.628 **

The curve fitting procedure used was not able to fit a curve of the specified form to the data from velocity measurements at Wainiha stream for S. stimpsoni 'with repeats.'

QUESTION AND ANSWER SESSION

Robert Kinzie

Smith: In the comparisons that you presented in this paper, were you comparing preference or utilization functions?

Kinzie: We compared preference functions and they were never the same. However, we had many of the same problems that people have been talking about here. To test preference functions, you would have to start out with the availability term squared, so you don't lose your denominator in the calculation of preference. We multiplied preference from one stream by availability in another. To arrive at "preference" in the second stream, in the context of this workshop, you have to do something to get availability back into the equation. I think that would defeat the purpose of this sort of an analysis. Gary Smith asked me if I was going to talk about utilization or preference functions. What I have been talking about is sort of halfway in between.

VERIFICATION OF HABITAT UTILIZATION CRITERIA FOR JUVENILE FALL CHINOOK IN THE NORTH FORK OF THE LEWIS RIVER, WASHINGTON

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ABSTRACT

Studies sponsored by Pacific Power & Light Company were conducted to evaluate the applicability of using published IFG probability-of-use criteria (Bovee 1978) to describe rearing habitat used by young-of-the-year fall chinook salmon in the Lewis River. Snorkel observations and subsequent point measurements of physical habitat occupied by juvenile fall chinook were made at river flows ranging between 2,000 and 6,000 cfs. Fry (25-50 mm) and juvenile (51-110 mm) habitat utilization data were collected for nose depth and velocity, total depth, mean column velocity, substrate, functional cover, object cover, and distance offshore. Site-specific criteria were developed via frequency analysis and compared with existing curves. Published IFG criteria differed substantially from the Lewis River criteria. Site-specific criteria were recommended for use in the subsequent Lewis River instream flow study.

INTRODUCTION

In relicensing the Merwin Hydroelectric Project (Figure 1), Pacific Power & Light Company (Pacific) desired to evaluate the potential benefits of a negotiated instream flow agreement with the Washington Departments of Fisheries and Game (WDF and WDG) on young-of-the-year Lewis River fall chinook salmon (*Oncorhynchus tshawytscha*). Pacific and WDF agreed to conduct a study using

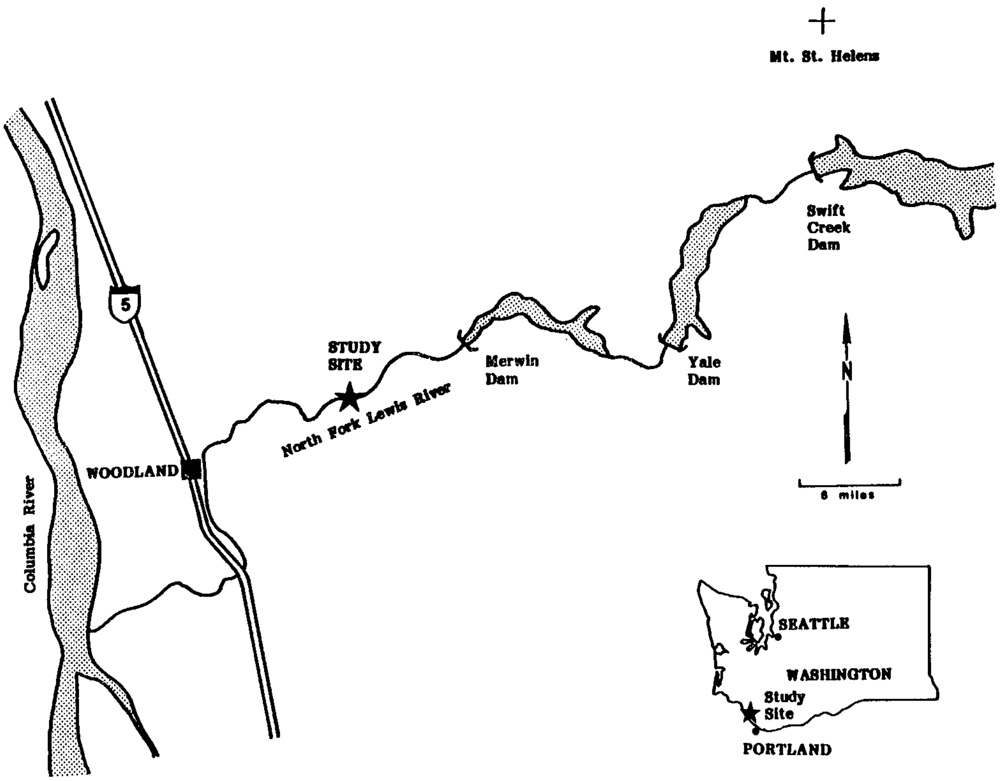

Figure 1. Map of Lewis River study area.

the Instream Flow Incremental Methodology (IFIM). In development of a consensus study plan, it was agreed that simulation of rearing habitat would use juvenile chinook probability-of-use criteria developed by IFG (Bovee 1978), after suitable verification (Leder and Campbell 1984).

Little work has been conducted to specifically develop or verify habitat criteria for fall chinook in western Washington. This paper describes the results of studies conducted to evaluate the applicability of using the published juvenile chinook curves to describe rearing habitat used by young-of-the-year Lewis River fall chinook.

METHODOLOGY

Snorkel observations of juvenile fall chinook were made in the Lewis River instream flow study reach (Figure 2) during May, June, and July 1984. This area contained habitat considered by WDF to be preferred by rearing fall chinook. It also included a diversity of habitat types available under different flow conditions, to provide fish with numerous combinations of depth, velocity, and other habitat variables.

Divers made observations while moving in an upstream direction, covering as much of the stream channel as possible. In mid-channel areas with high water velocities, divers conducted cross-stream observations while drifting downstream. When undisturbed juveniles were observed, divers estimated the

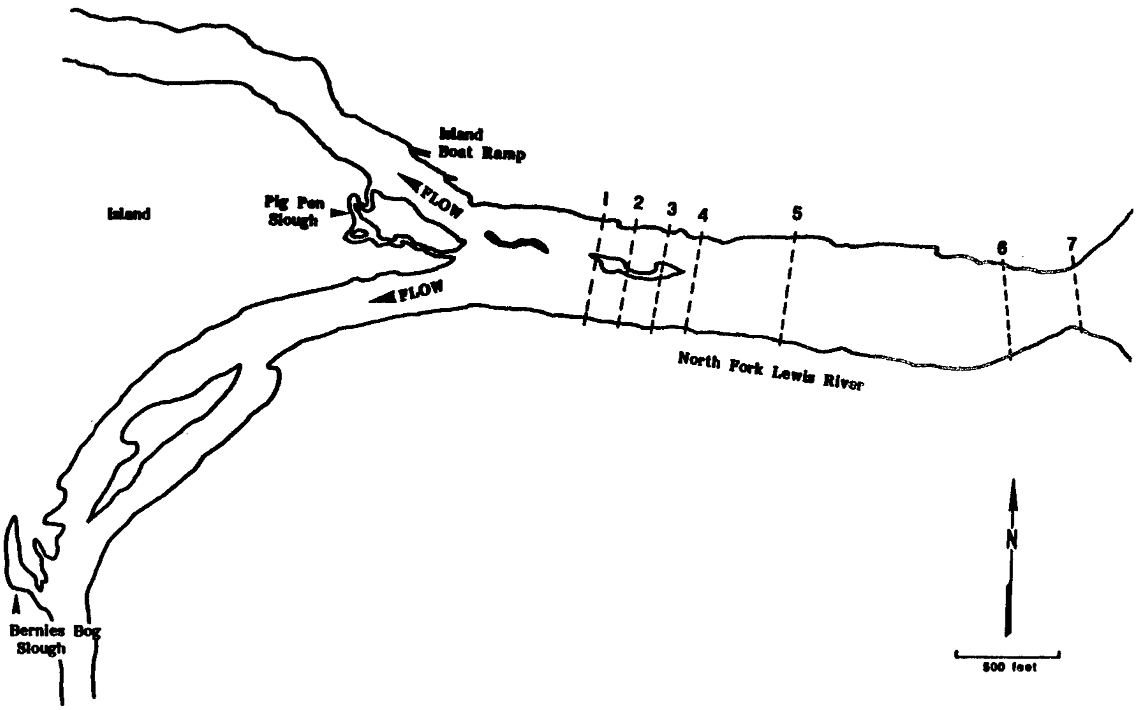

Figure 2. Lewis River instream flow study reach (transect locations indicated by numbered lines).

number of individuals present by species and size (nearest 5 mm) and marked the position with a weighted buoy. For each observation the following information was collected:

<u>Depth.</u> Both water depth and fish depth in the water column were recorded at each observation point. Depths were measured with either a standard 6-foot top-set wading rod or a 12-foot manual-setting measuring rod.

<u>Velocity.</u> Both mean column velocity and nose velocity of the fish were recorded at each observation point. Velocities were measured with a Swoffer model number 2100 current meter, which is designed to measure velocities between 0.1 and 25.0 fps with less than 2 percent error.

<u>Substrate.</u> Substrate in the vicinity (0.5 m radius) of the observation point was recorded according to the WDF standardized classification scheme (Table 1).

<u>Cover.</u> The relative value of cover for fish in the vicinity (0.5 m) of the observation point was estimated according to the classification scheme provided by Campbell et al. 1985 (Table 2). Objects providing the cover were also recorded.

<u>Distance Offshore.</u> Distance from the fish location to the adjacent bank or island was measured to the nearest foot.

Table 1. WDF substrate particle size codes for IFIM studies.

Code number	Description	Diameter mm	Diameter inches[1]
0	Organic detritus		[2]
1	Silt, clay	<2	[3] <0.1
2	Sand[3]	<2	<0.1
3	Small gravel	2-12	0.1-0.5
4	Medium gravel	12-38	0.5-1.5
5	Large gravel	38-76	1.5-3.0
6	Small cobble	76-152	3.0-6.0
7	Large cobble	152-305	6.0-12.0
8	Boulder	>305	>12.0
9	Bedrock		

[1]Rounded to nearest 0.5 inches.

[2]Material smaller than that which will provide cover.

[3]According to some authorities, the size break between sand and silt occurs at approximately 0.06 mm. Since the difference between 0.06 and 2.0 mm cannot be visually estimated in the field, it will be necessary for investigators to use their best judgment in determining whether these small particles are sand or silt.

For each sampling date, stream discharge (cfs), measured at the USGS Ariel Gage, and water temperature (°C) were recorded.

Location of fish observed by each diver was mapped to document distribution. Fish whose behavior appeared to have been influenced by a diver or support personnel were not sampled. To confirm diver estimates of fish length, fish were collected using a 6-m stick seine. Captured fish were anesthetized with tricane methane sulphonate (MS222) and a representative sample measured (fork length in mm). Length data collected by WDF during their extensive beach seining of the lower Lewis River in 1984 were also used to verify diver fish-length estimates.

Habitat data from all locations were combined, and frequency distributions for individual sets of depth, velocity, substrate, and cover were generated for various fish size classes. Frequency analysis was conducted using the histogram and univariate plot program in the BMDP statistical software library (BMDP 1981).

Table 2. Fish habitat cover code.

This three digit cover code was designed to describe the quality of habitat selected by individual fish. The three functional cover types include: (1) shelter from stream velocity, (2) visual isolation, and (3) light reduction. Each cover type has three potential relative degrees of protection: none, moderate, and major.

Relative degree of cover	Protection from stream velocity[1]	Visual isolation[2]	Light reduction[3]
None	0	0	0
Moderate	1	1	1
Major	2	2	2

[1]Reduced current provided by stream hydraulics (boulders, submerged vegetation, channel configuration, backeddies, etc.).

None = Exposed to the current
Moderate = Adjacent to current with slight protection
Major = Complete current protection (areas of little to no velocity; reverse or cross flows)

[2]Reduction in horizontal "line-of-sight."

None = Open
Moderate = Partially obscured
Major = Mostly obscured

[3]Reduced light provided by turbidity, overhanging vegetation, undercut banks, etc.

None = Bright
Moderate = Shade
Major = Dark

Curves were fit to the histograms of continuous variables according to the data clustering techniques presented in Bovee and Cochnauer (1977). Utilized habitat for discrete variables was tabulated as normalized frequency distributions. Final curves were compared to Bovee's (1978) published juvenile chinook curves to determine their applicability for use in the Lewis River.

Two night dives were conducted in the study reach to determine if juvenile behavior during evening hours differed from behavior observed during daylight.

Observational methods were the same, except no nocturnal habitat measurements were taken.

RESULTS

FIELD OBSERVATIONS

During the study, 552 point measurements were collected, representing 4,368 0+ age chinook. Observed chinook ranged in size from 25 to 110 mm. A frequency distribution of estimated fish lengths is provided in Figure 3. Estimated fish lengths compare favorably with actual measurements collected during each sampling trip (Table 3).

Chinook steadily progressed offshore into deeper, faster water as they grew in length. Because fry (25-50 mm) occupied distinctly different habitat than juvenile chinook (51-110 mm), habitat analyses were conducted separately for two size classes. Data collected during each sampling trip are summarized

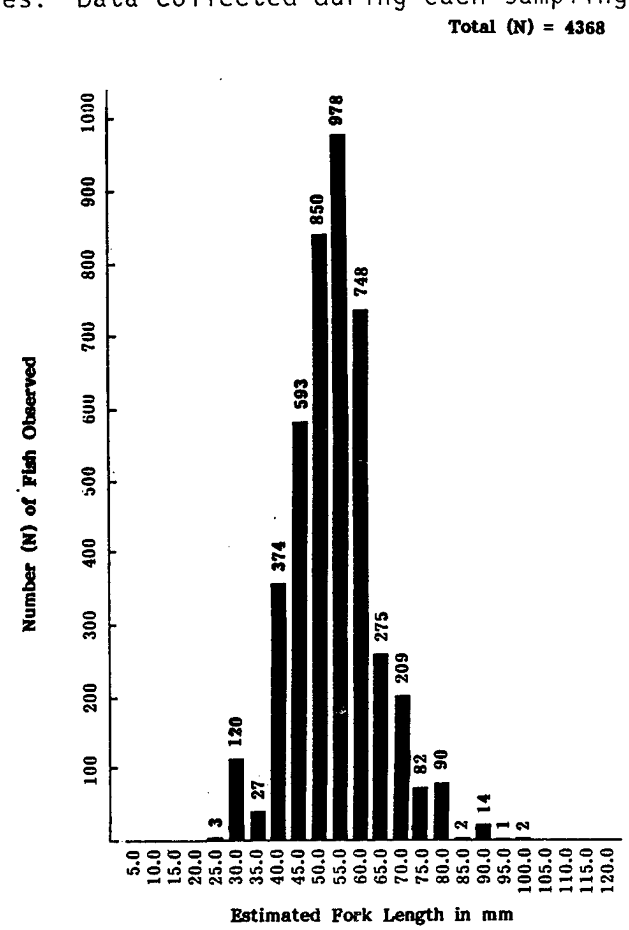

Figure 3. Frequency distribution of the young-of-the-year fall chinook salmon observed during the 1984 Lewis River snorkel surveys.

Table 3. A comparison of estimated and measured fish lengths collected during the survey.

Sampling date		Underwater estimated lengths	Measured lengths WDF[1]	Measured lengths Verification study
May 9 and 10, 1984	Mean :	42.5mm		
	Range:	25-65mm		
	N :	685		
May 30 and 31, 1984	Mean :	54.0mm	46.8mm	53.3mm
	Range:	35-75mm	43-66mm	40-86mm
	N :	1,915	28	46
June 11 and 12, 1984	Mean :	54.4mm	53.2mm	
	Range:	30-90mm	39-76mm	
	N :	722	750	
June 27 and 28, 1984	Mean :	60.6mm	50.7	59.4mm
	Range:	40-100mm	38-98	45-72mm
	N :	909	126	25
July 19 and 20, 1984	Mean :	58.8mm	56.0mm	
	Range:	30-110mm	36-113mm	
	N :	138	257	

[1]Measurements taken by Washington State Department of Fisheries of fish collected within the study reach during their 1984 juvenile tagging study.

according to these size classes in Table 4. Maps showing the location of young-of-the-year chinook observed each survey are presented in Figures 4 though 8.

The majority of fry were found in a narrow band along the stream margins, from 0 to 15 feet offshore. This zone was always inshore of an obvious velocity shearline. Fry occupied areas of low velocity with moderate degrees of cover. Velocity shelter created by the shoreline configuration and visual isolation provided by the shoreline and submerged vegetation were used most frequently, while shaded areas did not appear to be of importance. Chinook fry generally congregated in schools and moved throughout the water column. They most frequently used areas of shallow to moderate depth (0.5 to 3.0 feet).

Table 4. Mean range and peak values of habitat parameters measured during 1984 Lewis River snorkel surveys.

Parameter		May 9 & 10, 1984		May 30 & 31, 1984		June 11 & 12, 1984		June 27 & 28, 1984		July 19 & 20, 1984		Summary May 9 - July 20, 1984	
Discharge (cfs)	mean	5,850		6,000		4,520		3,160		2,050		4,320	
Temperature (°C)	range	7.8-8.3		9.4-10.0		10.6-10.6		11.7-11.7		13.9-13.9		7.8-13.9	
		Fry	Juvenile	Fry	Juvenile	Fry	Juvenile	Fry	Juvenile	Fry	Juvenile	Fry	Juvenile
Fork Length (mm)	mean	42	64	45	61	45	65	48	67	43	71	45 mm	66 mm
	range	25-50	55-75	35-50	55-75	30-50	55-90	40-50	55-100	30-50	55-110	25-50 mm	55-110 mm
Depth (ft)	mean	1.7	2.6	1.7	2.5	1.7	2.8	1.7	2.5	1.4	2.3	1.7 feet	2.6 feet
	range	0.5-3.7	1.5-4.5	0.5-3.5	0.7-6.5	0.7-3.2	1.0-7.2	0.5-7.2	0.7-7.2	0.5-3.2	0.7-5.5	0.5-7.2 feet	0.7-7.2 feet
Nose Depth (inches above streambed)	mean	6	6	6	5	4	5	4	6	2	3	5 inches	5 inches
	range	1-36	1-24	1-28	1-18	1-20	1-50	1-10	1-54	1-6	1-18	1-36 inches	1-54 inches
Mean Column Velocity (fps)	mean	.34	0.91	0.32	0.80	0.60	0.96	0.40	0.81	0.51	1.25	0.42 fps	0.91 fps
	range	0-2.7	0.0-1.4	0-1.4	0-2.7	0-2.70	0.2.70	0-1.40	0-2.90	0-1.40	.2-2.6	0-2.70 fps	0-2.90 fps
Nose Velocity (fps)	mean	0.22	0.46	0.26	0.40	0.29	0.47	0.29	0.47	0.25	0.60	0.26 fps	0.48 fps
	range	0-1.80	0-1.00	0-.95	0-1.30	0-1.0	0-1.30	0-0.80	0-1.25	0-1.00	.05-1.45	0.0-1.80 fps	0.0-1.45 fps
Dominant Substrate (code)	peak	0	5	1	5	2	5	5	5	9	5	5	5
	range	0-9	1-9	0-7	0-9	1-9	1-9	1-9	0-9	2-9	3-9	0-9	0-9
Cover 1 (code) (velocity shelter)	peak	2	1	2	1	1	1	1	1	1	1	1	1
	range	1-2	0-2	1-2	0-2	1-2	0-2	1-2	0-2	1-2	0-2	0-2	0-2
Cover 2 (code) (visual isolation)	peak	1	0	1	0	1	0	0	0	1	0	1	0
	range	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-1	0-1	0-2	0-2
Cover 3 (code) (light reduction)	peak	1	0	1	0	0	0	0	0	0	0	0	0
	range	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-2	0-1	0-1	0-2	0-2
Distance Offshore (ft)	mean	11	23	9	22	14	22	16	19	11	61	12 feet	26 feet
	range	1-65	1-60	1-60	1-65	1-70	2-85	3-50	2-85	9-50	2-120	1-70 feet	1-120 feet
Number of measurements		78	6	47	63	49	86	37	128	16	42	227	325

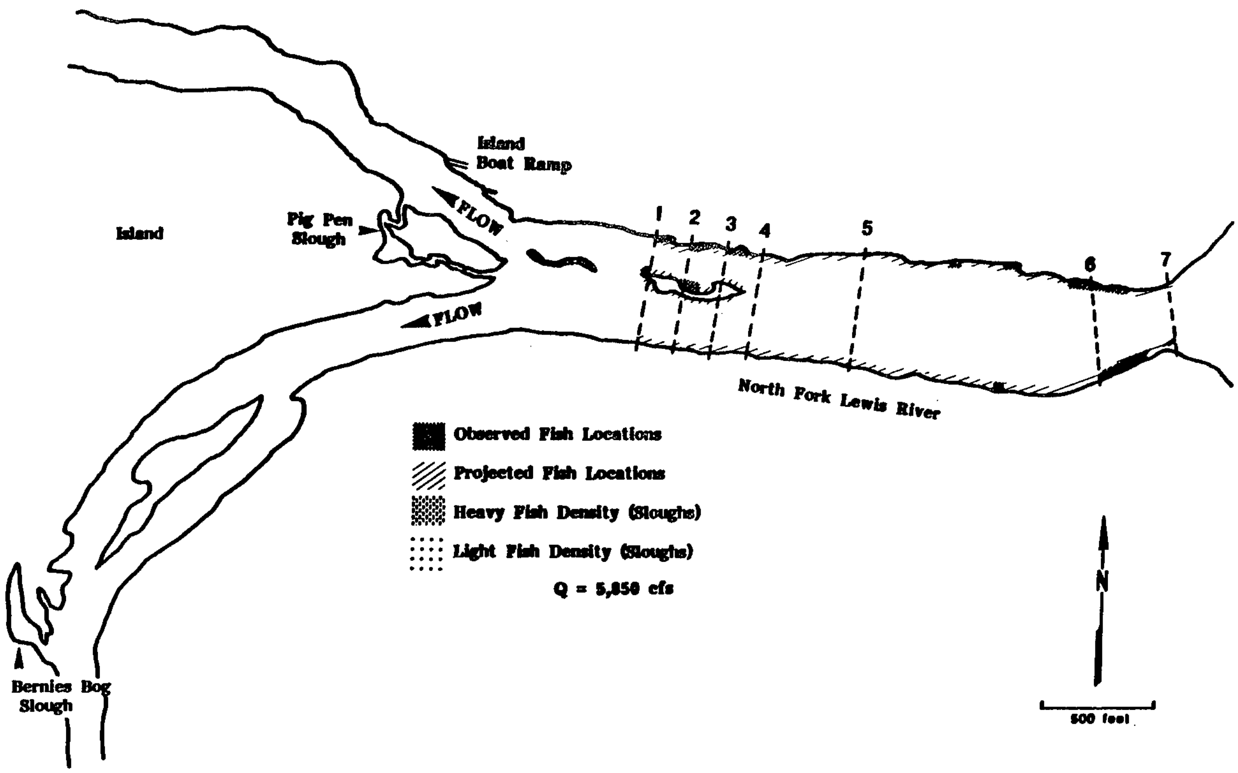

Figure 4. Juvenile chinook utilization (May 9 and 10, 1984).

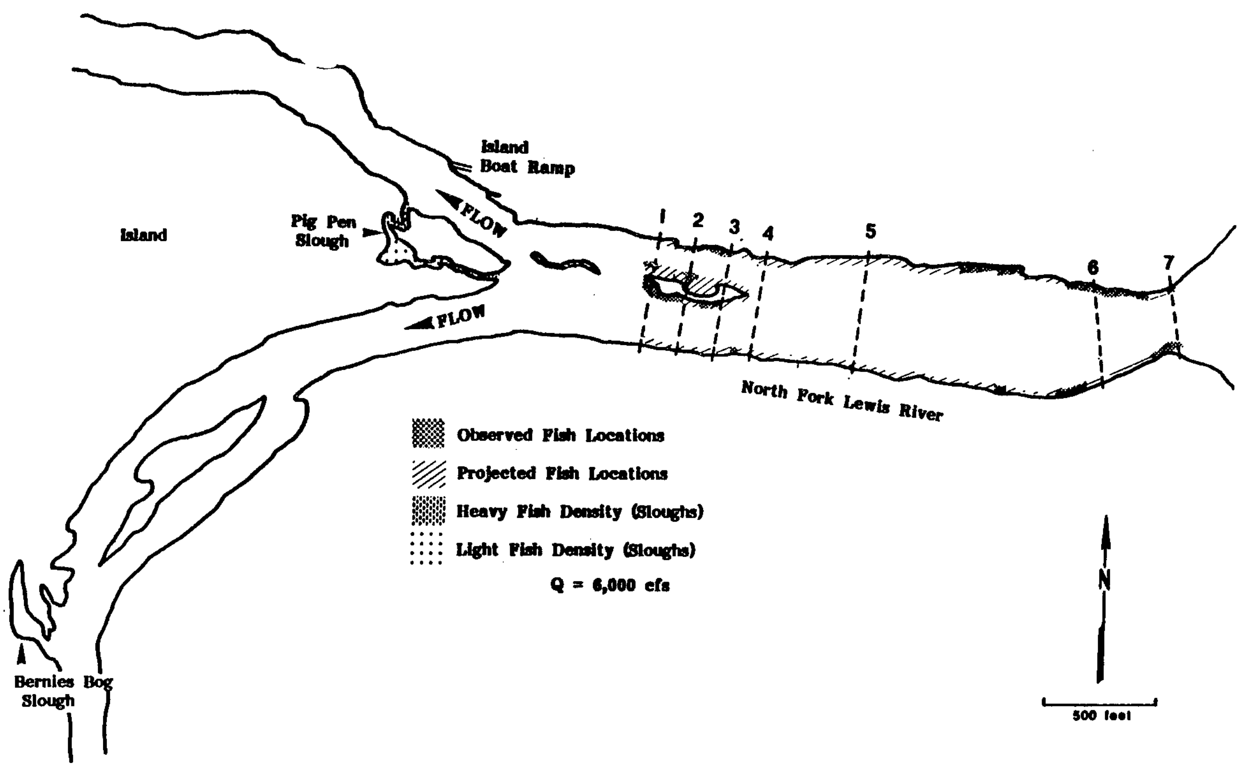

Figure 5. Juvenile chinook utilization (May 30 and 31, 1984).

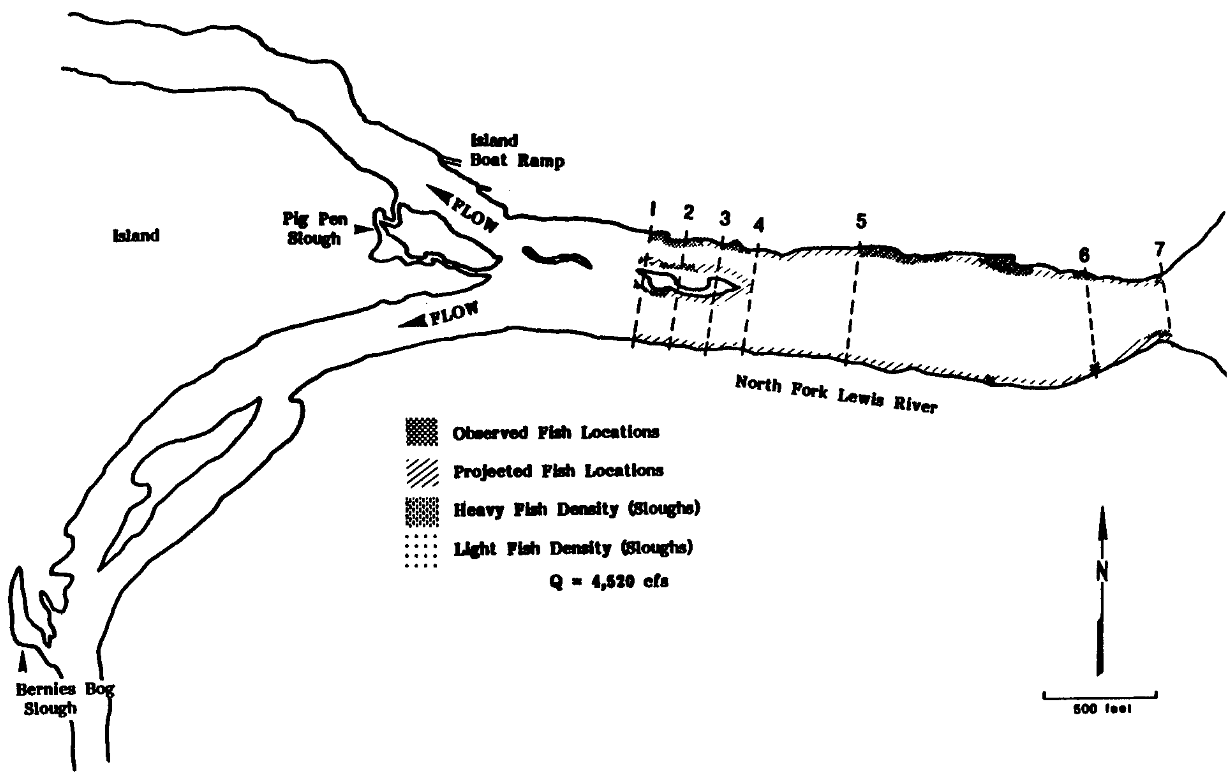

Figure 6. Juvenile chinook utilization (June 11 and 12, 1984).

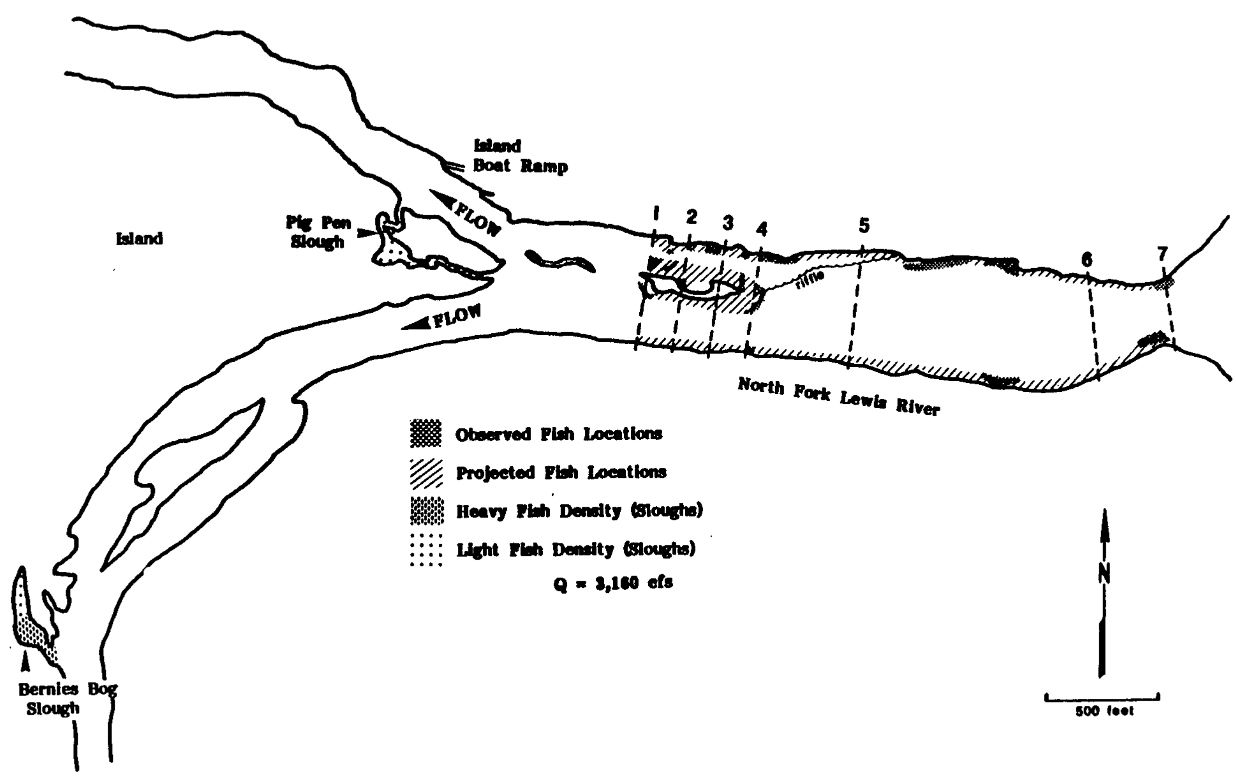

Figure 7. Juvenile chinook utilization (June 27 and 28, 1984).

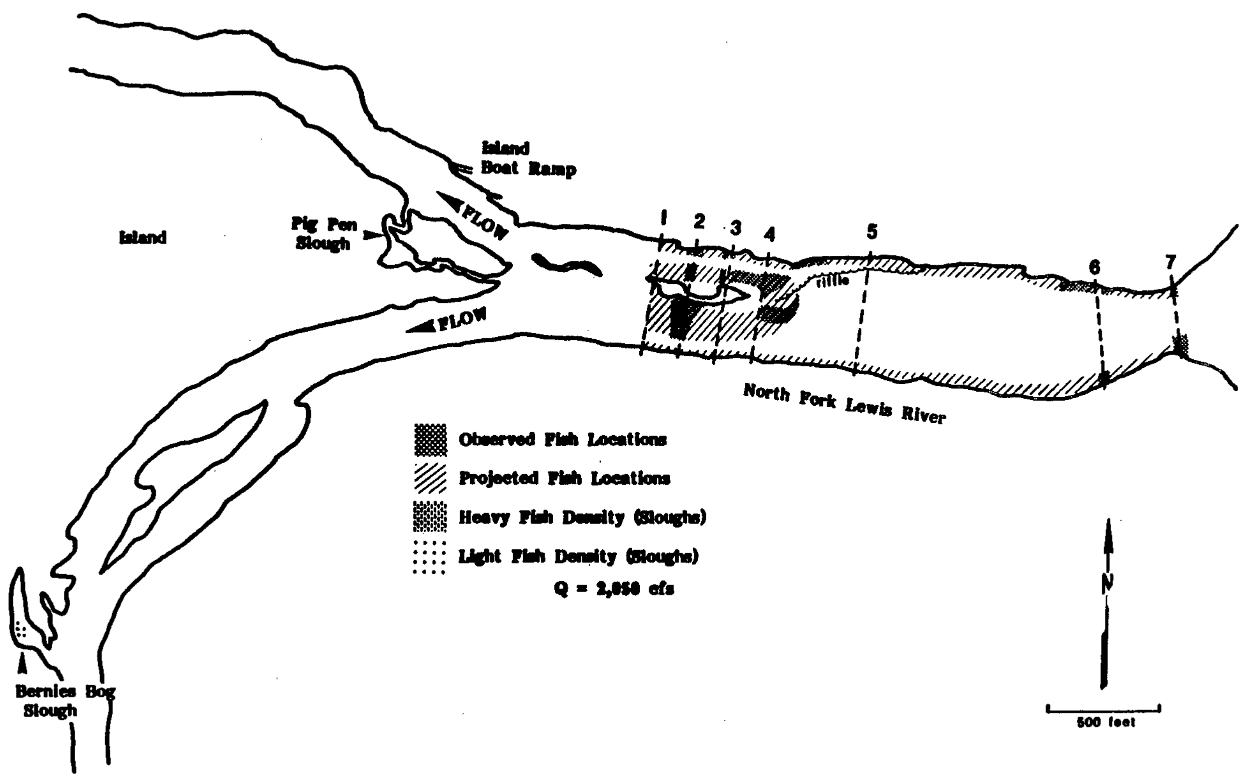

Figure 8. Juvenile chinook utilization (July 19 and 20, 1984).

Juvenile chinook occupied a broader zone than fry. The offshore boundary for juveniles appeared to be formed by either water greater than 7.0 feet or an increase in mean column velocity above 3.0 fps. The maximum distance juveniles were found offshore was 120 feet in July at the lowest river flow surveyed. Juvenile chinook inhabit areas possessing less cover than that of fry. Velocity shelter, either created by bottom roughness or shoreline configuration, seemed to be selected, whereas visual and light cover did not appear to be of major importance.

Although juveniles moved further offshore than fry, most remained in schools in low velocity areas. In water with moderate velocity, juveniles established territories near the stream bed and were encountered individually or in groups of two. Territorial juveniles maintained a position 1 or 2 inches off the bottom and moved briefly from these locations to capture food. These observations concur with the focal-point concept and territorial nature of salmonids in streams previously noted by other researchers (Kalleberg 1958; Keenleyside 1962; Wickham 1967; Edmundson et al. 1968; Hunter 1973; Dettman 1977; Rimmer et al. 1983).

Observations were made in high velocity, mid-channel areas during each field survey. No 0+ age chinook were observed in these high velocity (>3.0 fps) areas. Species noted in fast waters offshore included adult cutthroat, rainbow, and steelhead trout, chinook salmon, mountain whitefish, northern squawfish, peamouth chub, largescale sucker, and sculpin, as well as 1+ age or older coho and steelhead smolts.

At night, young-of-the-year chinook were found further inshore than during the day. Fry were found within 4 feet of shore, often in water as shallow as 1 inch. Juveniles were not observed further than 15 feet offshore. In comparison, during the same day, fry and juveniles had been dispersed up to 24 and 120 feet offshore, respectively. The maximum velocity used at night was below 0.5 fps. Fry and juveniles were often observed lying motionless either in contact with or close to the bottom. Large trout and smolt-sized salmonids were also observed well inshore from their daytime mid-channel positions.

HABITAT CRITERIA VERIFICATION RESULTS

Observed Utilization

a. Chinook fry. During the field study, 227 point measurements were collected, representing the locations of 1,967 observed fry. Fry ranged in size from 25 to 50 mm and averaged 45 mm in length.

Depth. Fry utilized water depths ranging from 0.4 feet to 7.2 feet. The depth interval with the greatest utilization was 1.5 feet. Both a histogram and a curve representing depth utilization are shown in Figure 9.

Velocity. Chinook fry utilized a narrow range of mean column velocities (0.0-2.7 fps). Maximum utilization occurred at 0.0 fps. Fry nose velocities ranged between 0.0 and 1.8 fps and the greatest utilization occurred at 0.0 fps. A histogram and curve representing mean column velocity utilization is shown in Figure 10.

Substrate. Chinook fry utilized the entire range of substrate types available in the Lewis River. The frequency of utilized occurrence for the various substrate categories are tabulated in Table 5. Large gravel was used most often.

Functional cover. Fry utilized all possible cover combinations except locations without velocity shelter (code 0). The most utilized cover combination represented locations with moderate velocity and visual cover with no light reduction cover. A summary of the range of utilized cover combinations is presented in Table 6.

Object cover. Chinook fry utilization of eight object cover types is provided in Table 7. The most frequently used type was the edge effect offered by shoreline configuration. In comparison, the second most frequently used cover type, submerged grasses, was used approximately half as often as the shoreline configuration.

Distance offshore. Fry were located immediately adjacent to the shoreline and up to 70 feet offshore. Most fry, however, were found in a narrow band within 15 feet of shore. This distribution changed little throughout the study period.

b. Chinook juveniles. During the study, 325 point measurements were collected representing the locations of 2,401 observed juveniles. Juveniles ranged in size from 55 to 110 mm and had an average length of 66 mm.

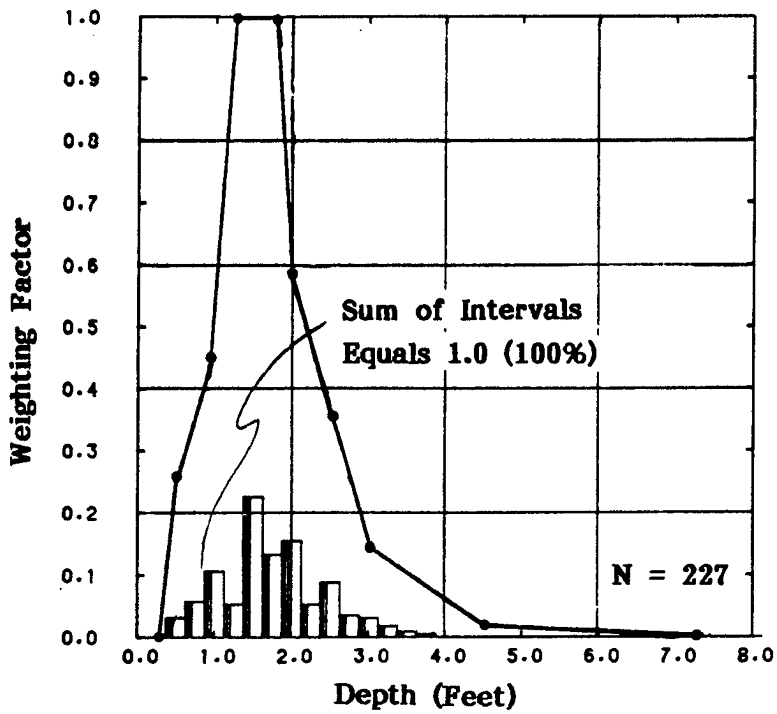

Figure 9. Fall chinook fry depth utilization curve (histogram represents normalized raw data).

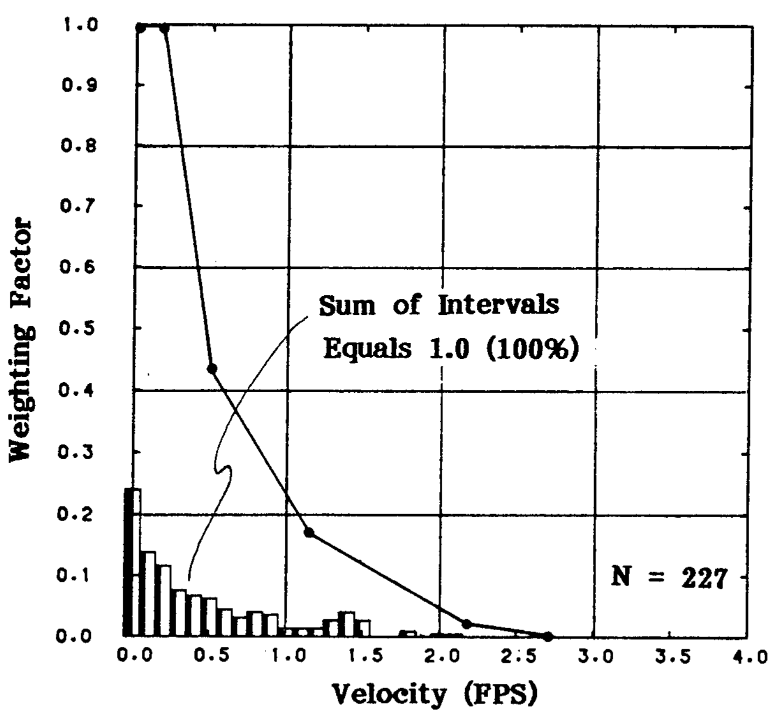

Figure 10. Fall chinook fry velocity utilization curve (histogram represents normalized raw data).

Table 5. Frequency of dominant substrate types utilized by chinook fry in the Lewis River.

Dominant substrate code		Number of measurements	Normalized utilization
0	Detritus	29	.56
1	Silt	35	.67
2	Sand	36	.69
3	Small gravel	6	.12
4	Medium gravel	26	.50
5	Large gravel	52	1.00
6	Small cobble	15	.29
7	Large cobble	2	.04
8	Boulder	0	.00
9	Bedrock	26	.50
	TOTAL	227	

Table 6. Frequency of functional cover types utilized by chinook fry in the Lewis River.

Function cover type	Number of measurements	Normalized utilization
Velocity shelter		
0) No shelter	0	.00
1) Moderate shelter	126	1.00
2) Major shelter	101	.80
Visual isolation		
0) Open to view	67	.55
1) Partly obscured	122	1.00
2) Mostly obscured	38	.31
Light reduction		
0) Bright	114	1.00
1) Shade	79	.69
2) Dark	34	.30
TOTAL	227	

Table 7. Frequency of object cover types utilized by chinook fry in the Lewis River.

Object cover type	Number of measurements	Normalized utilization
Streambed	30	0.40
Overhead vegetation	39	0.52
Surface turbulence	-	-
Shoreline configuration	75	1.00
Submerged vegetation (grasses or willows)	40	0.53
Submerged wood	10	0.13
Root wad	10	0.13
TOTAL	204	

Depth. Juvenile chinook utilized depths ranging from 0.7 to 7.2 ft. Maximum utilization occurred at a depth interval of 2.5 ft. Both a histogram and a curve representing depth utilization are shown in Figure 11.

Velocity. Mean column velocities utilized by the juveniles showed peak utilization at 0.4 fps, and ranged from 0.0 to 2.9 fps. Nose velocities at juvenile locations ranged between 0.0 and 1.5 fps. A histogram and curve for mean column velocity utilization appears in Figure 12.

Substrate. Chinook juveniles utilized the full range of substrate types available in the Lewis River. A list of the various substrate categories and the frequency of utilization are shown in Table 8. Of available substrate types, large gravel was used most often.

Functional cover. Juvenile chinook utilized all possible cover combinations to some degree. The most utilized cover combination represented a location with moderate velocity cover and no visual or light cover. A summary of the range and frequency of utilized cover types is presented in Table 9.

Object cover. Juvenile utilization of eight object cover types is provided in Table 10. The most frequently used type was substrate providing velocity shelter due to roughness. Shoreline configuration was the second most often used object type.

Distance offshore. Juveniles were typically found within 25 feet and up to a maximum of 85 feet offshore during the early portion of the study when river flows ranged between 3,000 and 6,000 cfs (Table 4). At 2,050 cfs in mid-July, juveniles were located a maximum of 120 feet and averaged 61 feet offshore.

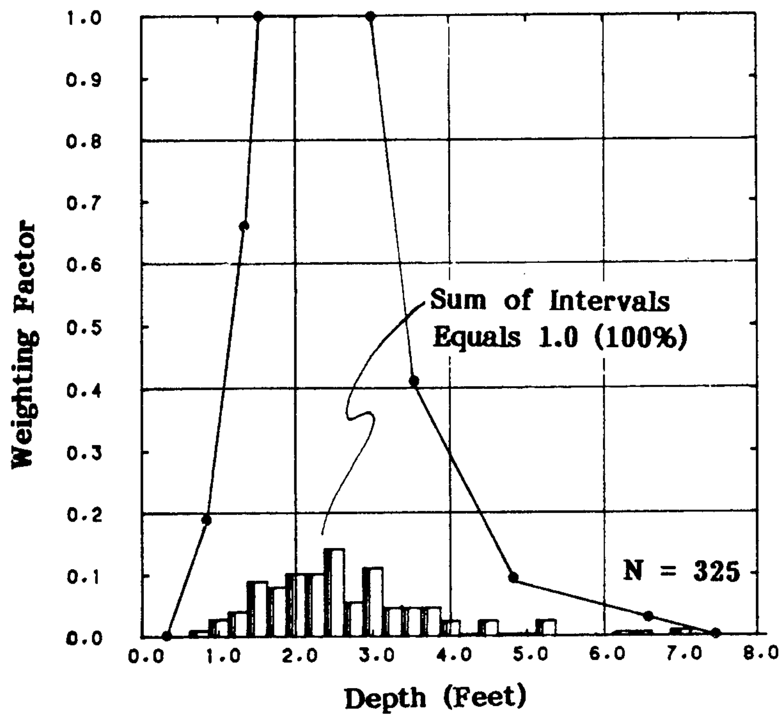

Figure 11. Juvenile fall chinook depth utilization curve (histogram represents normalized raw data).

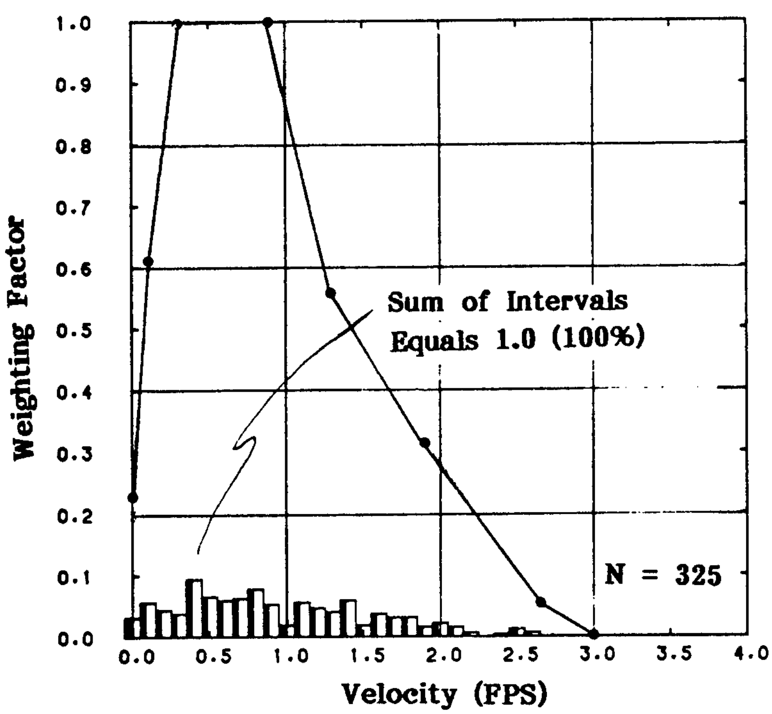

Figure 12. Juvenile fall chinook velocity utilization curve (histogram represents normalized raw data.

Table 8. Frequency of dominant substrate types utilized by juvenile chinook salmon in the Lewis River.

Dominant substrate code		Number of measurements	Normalized utilization
0	Detritus	2	.02
1	Silt	8	.08
2	Sand	49	.51
3	Small gravel	17	.18
4	Medium gravel	55	.57
5	Large gravel	97	1.00
6	Small cobble	50	.52
7	Large cobble	9	.09
8	Boulder	1	.01
9	Bedrock	37	.38
	TOTAL	325	

Table 9. Frequency of functional cover types utilized by juvenile chinook in the Lewis River.

Function cover type	Number of measurements	Normalized utilization
Velocity shelter		
0) No shelter	23	.08
1) Moderate shelter	274	1.00
2) Major shelter	28	.10
Visual isolation		
0) No isolation	227	1.00
1) Moderate isolation	83	.37
2) Major isolation	15	.07
Light reduction		
0) No reduction	243	1.00
1) Moderate reduction	58	.24
2) Major reduction	24	.10
TOTAL	325	

Table 10. Frequency of object cover types utilized by juvenile chinook in the Lewis River.

Object cover type	Number of measurements	Normalized utilization
Streambed	87	1.00
Overhead vegetation	37	0.43
Surface turbulence	4	0.05
Shoreline configuration	49	0.56
Submerged vegetation (grasses or willows)	31	0.36
Submerged wood	4	0.05
Root wad	2	0.02
TOTAL	214	

COMPARISON WITH EXISTING CRITERIA

Data collected in the Lewis River are compared below to existing depth, velocity, and substrate criteria for juvenile chinook salmon (Bovee 1978). The published criteria were based on 58 observations of 0+ age summer chinook ranging between 32 and 117 mm from two creeks in Idaho (Everest and Chapman 1972), and approximately 100 measurements of spring and fall chinook (50-150 mm) locations in numerous rivers and creeks in Oregon (Oregon State Department of Game 1969). These two data sets were combined, and criteria were developed for juvenile chinook.

Nose velocity and cover criteria for young-of-the-year (fry) chinook have not been previously published. Therefore, only depth, mean column velocity, and substrate data are discussed. Because of the noted behavioral difference between fry and juveniles, it was important to compare the Lewis River fry data with the published juvenile chinook criteria.

Chinook Fry

Depth. The curve representing fry depth utilization in the Lewis River is similar to the existing probability-of-use criteria (Bovee 1978) for chinook juveniles in the shallow end of the curve. The utilization curve departs markedly from the existing curve at depths over 2 feet. The Lewis River utilization curve shows decreasing use of areas over 2 feet deep and little to no use in areas over 3 feet deep. The existing curves, however, do not indicate a decrease in use as water depths increase (Figure 13).

Mean column velocity. The curve representing fry velocity utilization in the Lewis River differs greatly from the existing probability-of-use criteria.

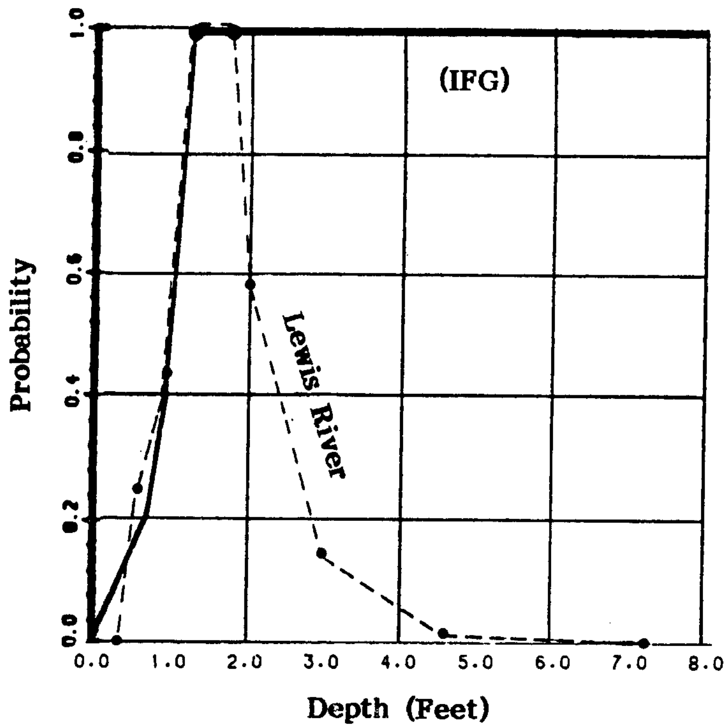

Figure 13. Comparison of fry depth utilization data with IFG probability-of-use criteria.

The utilization curve shows maximum velocity utilization at 0.0 fps and virtually no use at velocities greater than 2.0 fps. Conversely, the existing velocity criteria show no utilization at 0.0 fps, maximum utilization at 0.7 fps, and no utilization of mean column velocities over 3.0 fps (Figure 14).

Substrate. The published substrate criteria indicate little to no use of sand or smaller substrate particle sizes; heavy use of gravel, cobble, and boulder; and moderate use of bedrock. In the Lewis River, fry exhibited moderate use of detritus, silt, sand, medium gravel and bedrock; heavy use of large gravel; and little to no use of cobble and boulders. A comparison of the utilization frequencies between dominant substrate types of the two codes is provided in Table 11.

Chinook Juveniles

Depth. The curve representing juvenile depth utilization in the Lewis River is very similar to the existing probability-of-use criteria in shallow depths. Lewis River utilization data show decreasing juvenile use as depths increase over 3 feet, whereas the existing criteria suggest no decrease in use as water depths increase (Figure 15).

Mean column velocity. The curve representing juvenile velocity utilization in the Lewis River is similar to, but somewhat broader than, the existing probability-of-use criteria. The existing criteria indicate no use of 0.0 velocity, whereas the site-specific data indicate appreciable utilization of very low velocities (Figure 16).

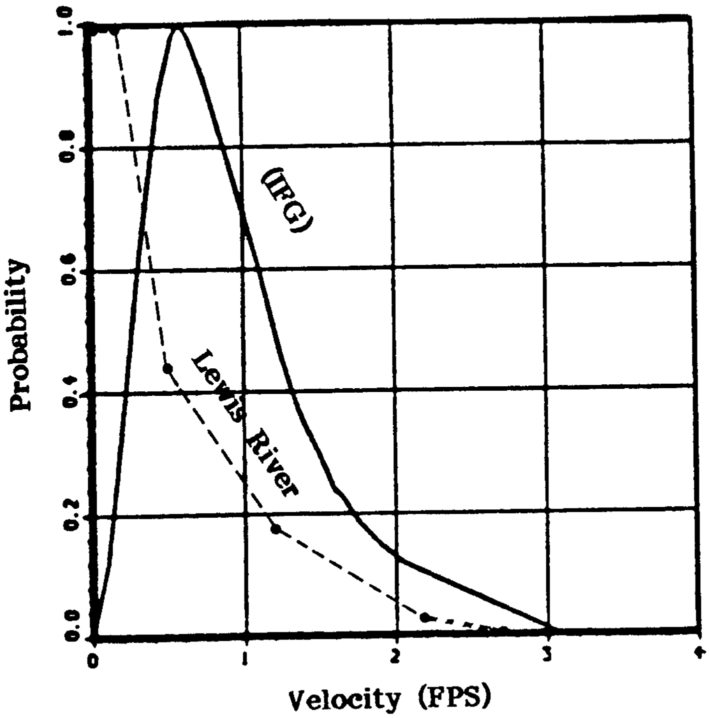

Figure 14. Comparison of fry velocity utilization data with IFG probability-of-use criteria.

Table 11. Comparison of dominant substrate types utilized by 0+ age chinook salmon in the Lewis River with IFG probability-of-use criteria.

Substrate type	IFG code	IFG criteria Juvenile	WDF code	Lewis River Data Fry	Lewis River Data Juvenile
Detritus	1	0.00	0	0.56	0.02
Mud/soft clay	2	0.00	1	0.67	0.08
Silt	3	0.02	1	0.67	0.08
Sand	4	0.06	2	0.69	0.51
Small gravel	5	0.90	3	0.12	0.18
Medium gravel	5	0.90	4	0.50	0.57
Large gravel	5	0.90	5	1.00	1.00
Small cobble	6	1.00	6	0.29	0.52
Large cobble	6	1.00	7	0.04	0.09
Boulder	7	0.95	8	0.00	0.01
Bedrock	8	0.65	9	0.50	0.38

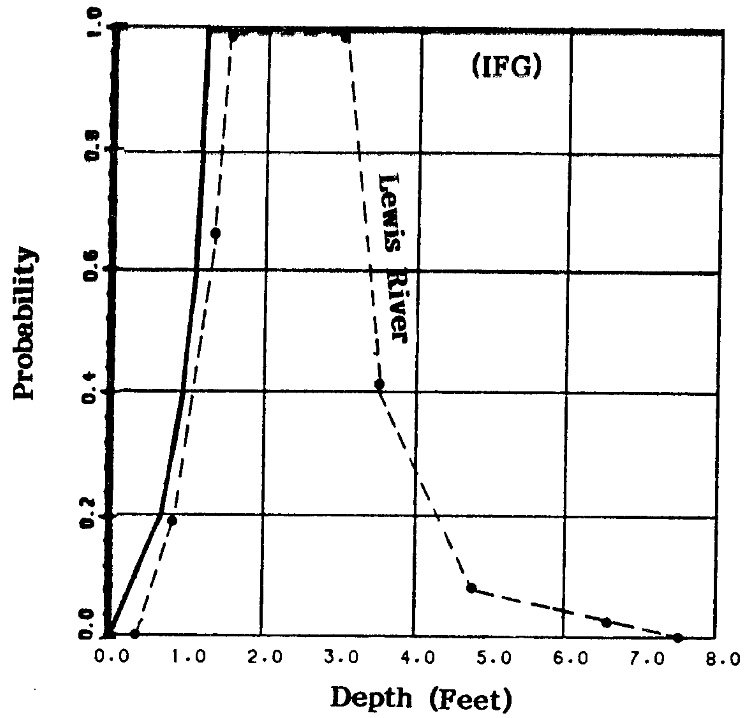

Figure 15. Comparison of juvenile depth utilization data with IFG probability-of-use criteria.

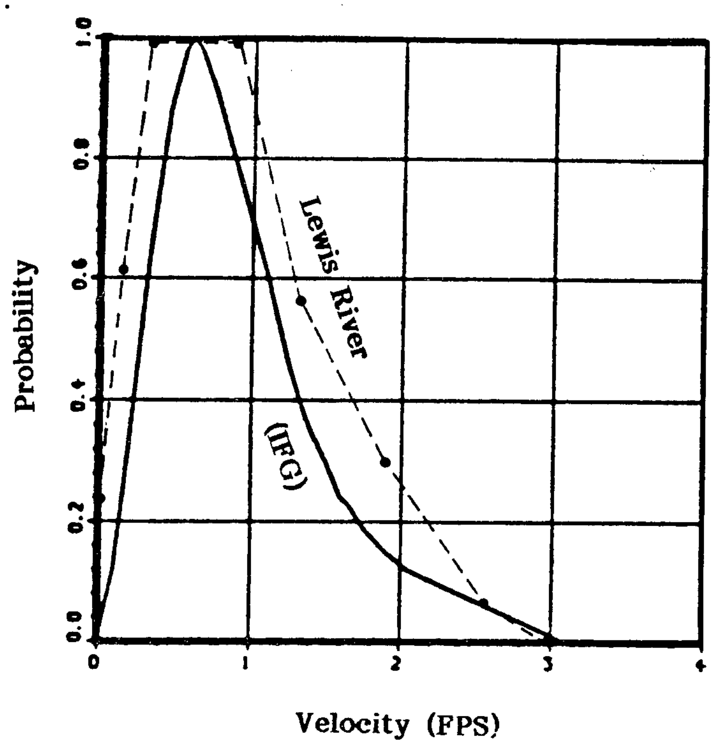

Figure 16. Comparison of juvenile velocity utilization data with IFG probability-of-use criteria.

Substrate. The published criteria indicate little to no use of sand and smaller substrate particle sizes; heavy use of gravel, cobble, and boulder; and moderate use of bedrock. In the Lewis River, juvenile chinook exhibited little use of detritus, silt, large cobble, and boulder; moderate use of sand to medium gravel, small cobble, and bedrock; and heavy use of large gravel. Utilization frequencies of the two substrate codes are compared in Table 11.

DISCUSSION

CHINOOK FRY

Velocity appeared to be the most important physical parameter affecting fry distributions in the river. Most fry used mean column velocities less than 1.0 fps. Selection of low velocity areas is apparently related to fish length, and thus swimming performance, as well as to energy optimization.

Fry were found most often in water less than 2 feet deep, less frequently in depths of 2 to 4 feet, and rarely in water greater than 4 feet deep. Most deep water zones are associated with velocities rarely utilized by fry (>2.0 fps). Lack of deep water use also may be the result of competition with larger chinook juveniles or predation by larger fish.

The tendency for chinook fry to concentrate in slow, shallow water along stream margins has been previously noted by Chapman (1966) and Lister and Genoe (1970). In the Lewis River, the nearshore distribution of fry is apparently a response to velocity and depth distributions. When slow velocities and relatively shallow depths extended further offshore, chinook fry were present.

With respect to vertical distributions, fry were found at all levels in the water column. In nearshore areas where there was little to no vertical difference in velocities, fry cruised throughout the water column, often in schools. However, as water depth and velocity increased, fry became more oriented to the bottom. In these situations, fish nose velocities were always less than mean column velocities.

Substrate in the Lewis River is uniform small to large cobbles with a thin mat of periphyton. The only exception is along the river margin, where gravel, sand, and silt settle on the stream bed and occasional bedrock outcrops occur. Substrate types generally used most frequently by fry were the ones along the stream margins. Utilized substrate appears to be a function of the river velocities used by rearing fry and the types of substrate present in the river, rather than selection of a specific substrate characteristic.

CHINOOK JUVENILES

Juvenile chinook were more widely distributed offshore than fry. They did not occupy shallow areas (<0.7 feet). They were found most frequently in areas of moderate depth (1.5-4.0 feet) and velocities (0.0-1.5 fps). Their

offshore distribution was generally bounded by deep (<7.0 feet) or fast (>3.0 fps) water. The offshore movement of chinook juveniles has been associated with growth and the need for larger prey items and increased territories (Chapman 1966; Lister and Genoe 1970). The culmination of this move offshore was the selection of territorial focal points. The movement offshore and the scattered distribution of the juveniles may be helpful in reducing interspecific competition between chinook of similar size.

With respect to vertical distributions, juveniles are found in schools throughout the water column in low velocity areas (<1.0 fps) and within a few inches of the streambed in regions of moderate velocity (1.0-3.0 fps). Fish nose velocities were substantially less, often half the magnitude of the mean column velocity. It appears as juvenile chinook grow and swimming performance improves, they move offshore to regions of higher velocity, possibly to take advantage of drifting food resources. They use discontinuities in the substrate as shelter from the current. Areas providing visual isolation and light reduction were not used frequently by juveniles, and they do not appear to be a habitat factor in feeding locations.

OFFSHORE DISTRIBUTION

Chinook distributions did not remain constant throughout the May to July study period. A general movement further offshore was observed as the study progressed (Figures 4 through 8). Although offshore movement is expected as chinook grow, lower water velocities resulting from decreased flow were most likely a major factor in this shift. A steady widening of the nearshore areas available to chinook fry and juveniles was observed as river discharge decreased from 6,000 to 2,000 cfs. During the lowest flow, these zones of appropriate depth and velocity extended several hundred feet offshore. The increased distributions were primarily a factor of reduced water velocities over gently sloping bottom areas. In steep bank areas, available habitat remained constant throughout the range of river flows sampled.

NIGHT OBSERVATIONS

Night observations suggest a major diurnal shift occurs in habitat used by young-of-the-year chinook and other salmonids present in the Lewis River. Evening use of nearshore shallow, low velocity areas by 0+ age chinook has been previously documented (Chapman and Bjornn 1969; Edmundson et al. 1986). These investigators concluded that the fish move inshore to rest, to reduce the likelihood of downstream displacement, and to reduce energy expenditure during darkness when feeding efficiency is poor. Size segregation of fish suggests the diurnal habitat shift exhibited by young-of-the-year chinook may be, in part, a response to predator avoidance or competition with larger salmonids.

CONCLUSIONS AND RECOMMENDATIONS

During snorkel surveys in the North Fork of the Lewis River, at flows between 2,000 and 6,000 cfs, observers noted wild young-of-the-year fall chinook appeared to be segregated in the river according to size classes. Fish larger than 50 mm occupied higher velocity areas further offshore than smaller fish. Small chinook fry schooled in shallow, low velocity water along the stream margins. Larger fish established feeding territories within a few inches of the streambed in regions of moderate depth and velocity. Fish distributions in the river, most likely, were in response to balancing feeding opportunities with avoiding predators and reducing energy expenditure. Fish length, and thus swimming performance, appears to be the dominant factor in fish distribution. A diurnal shift in the types of habitat used by salmonids was observed in the Lewis River. All size classes moved nearshore into shallow, low velocity areas during periods of darkness. Fish were observed resting on the streambed at night. Size segregation was still apparent; chinook fry were found immediately adjacent to shore, often in only a few inches of water, while juveniles were located up to 15 feet offshore in water less than 1.5 feet deep.

Results of physical habitat measurements (depth, velocity, substrate, cover, and distance offshore) at observed locations of 1,967 fry and 2,401 juvenile fall chinook indicate:

- Fry most frequently used areas within 15 feet of shore, depths less than 2 feet, mean column velocities less than 1.0 fps, all available substrate types, and moderate velocity and visually sheltered positions.

- Juveniles were most frequently found within 25 feet of shore, in depths of 1 to 4 feet, in mean column velocities less than 2.0 fps, over all substrate types, and in moderate-velocity, sheltered positions.

Based on the narrow range used and the small degree of variance associated with velocity measurements, it appears stream velocity is the most important physical parameter affecting distributions of young-of-the-year fall chinook in the Lewis River. Similarly, depth was a valuable parameter in determining the location of rearing chinook. Cover appeared to have some importance, but much less importance than velocity or depth. Of the habitat characteristics measured, substrate appeared to be the least determining factor for rearing chinook.

Habitat criteria information for young-of-the-year fall chinook salmon were developed via frequency analysis of site-specific data and compared with published probability-of-use criteria for juvenile chinook. The Lewis River data differed substantially from published criteria. Because the habitat frequency data of 227 fry and 325 juvenile point measurements represent excellent criteria and because site-specific utilization data represent the

best available information to describe physical habitat suitability, the Lewis River data were recommended for use in the subsequent PHABSIM analysis.

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QUESTION AND ANSWER SESSION

Ron Campbell

Smith: Could you review your findings with respect to cover?

Cambell: Our findings indicate that fry select velocity shelters and visual isolation. They often use submerged vegetation. Coho stay on shore until they are about 50 mm long. The chinook seem to move out when they are a little bit smaller.

Aceituno: Are they keying on cover or velocity?

Campbell: I believe that they are keying on velocity.

Caldwell: Could you repeat the basis for your conclusion that they are keying on velocity.

Campbell: When you look at the velocity distribution in the stream and how the fish are using it, the narrow range and variability of the data indicates to me that velocity is very important. If it were not, I would expect a wider range with a larger variance.

Barrett: Have you considered stratifying your data into daytime and nighttime observation?

Campbell: Certainly, but we don't really have enough nighttime observations to derive separate curves. We have our own personal observations and a few spot measurements.

Aceituno: What additional information do you have on nighttime migration of these species?

Cambell: I have seen reports that have suggested that fish come in from fast water to rest in shallow water at night. I know that invertebrate drift is more abundant at night, but perhaps they can't see the organisms quite as well. Chapman and Everest, among others, have suggested that inshore migration is to avoid downstream displacement, but I don't think that is the case in this situation.

Bruya: Were the environmental conditions, such as cloud cover and the phase of the moon, the same for all your night dives?

Campbell: We had three night dives, but I can't remember what the conditions were. I'm fairly certain that they were consistent during that time period.

Bruya: That part of the Lewis River can be very dark. But with a full moon there could be considerable incident light on the river, unless there was complete cloud cover.

Campbell: That's true, but when we use dive lights at night, we don't necessarily scare the fish at all. In fact, they tend to start feeding once they see light.

Bovee: Do you have any clues as to why your curves came out so different from the IFG curves?

Campbell: Several. The IFG curves are based on literature data from a number of different streams. There may have been different races involved and there weren't really that many observations. In our work, we have always seen the depth curve tail off. It could be that when the original criteria were assembled, it was assumed that once a certain depth threshold was passed, it didn't matter anymore. I think this just points out that when people are doing this sort of work, they have to document their methods and assumptions very carefully.

Leonard: I would like to review how you do your snorkel counts in very shallow water. In shallow riffles, where your peripheral vision is severely reduced and your body is sticking out of the water, it seems to me that you would have quite a tendency to disturb fish.

Campbell: We probably hit our minimum depth in the tail ends of our pools. As long as you can get your face mask under water you can see things pretty well. We felt that we had quality observations in water three inches deep or greater. As long as you remain stable, disturbance of the fish will be minimal.

HABITAT AVAILABILITY CONSIDERATIONS IN THE DEVELOPMENT OF SUITABILITY CRITERIA

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INTRODUCTION

The most critical elements of the PHABSIM model are the habitat suitability criteria used to translate physical characteristics of streams and rivers, such as depth and velocity, into indices of habitat quality. Through the evolution of the PHABSIM model, the source of the criteria has changed dramatically. The earliest use of suitability criteria in the context of a PHABSIM-type model occurred in relation to an earlier methodology developed by Waters (1976). The depth and velocity criteria used in this method were derived from professional judgment and were thought of as measures of the relative value to the fish in terms of habitat quality. Suitability criteria used in early applications of the PHABSIM model were referred to as probability-of-use curves (Bovee 1978) and were derived from a variety of sources including professional judgment, results of laboratory experiments, and field observations.

Most habitat suitability criteria used in the PHABSIM model today have been developed from direct observations of the velocities, depths, and other physical characteristics in natural settings where fish were observed. The observations are generally displayed as frequency histograms, invoking the assumption that the physical conditions most frequently observed in the vicinities of fish are those most preferred. However, if insufficient "ideal" habitat was available in the natural setting to accommmodate the preferences of all the fish observed, some--or even all--of the fish might have been occupying less-than-ideal habitat, resulting in biased suitability criteria that do not reflect actual preference.

To eliminate this environmental bias, Bovee (1986) recommended that data on the amount of each type of habitat present (availability data) be collected concurrently with data on microhabitat at the location of the fish (utilization

data), and that the habitat availability data be used to modify the utilization data. The form of modification recommended, based on the work of Voos (1980), Baldridge and Amos (1981), and others, consists of dividing the frequency distribution of the habitat characteristics in the vicinity of the fish by the frequency distribution of the habitat characteristics in the environment available to them. This treatment of the data is equivalent to the commonly used measure of food selection known as the forage ratio, R/P, where R is the relative number of prey of a particular taxon eaten (observations of utilization) and P is the relative number of organisms of that taxon in the environment (availability). DeGraaf and Bain (1986) have applied this sort of correction to habitat suitability for riverine fish species; Schlagenhaft and Murphy (1985), for lake-dwelling populations.

Moyle and Baltz (1985) developed similar "electivity" (corrected habitat utilization) criteria for five species of riverine fish in California, using a modification of the Ivlev (1961) index of electivity that was developed by Jacobs (1974): (R-P)/(R+P-2PR). The Ivlev index is formulated as (R-P)/(R+P).

The purpose of this analysis is to investigate the appropriateness of using the forage ratio model, Ivlev's electivity index model, or the Jacobs model as tools in developing habitat suitability criteria. We begin with an evaluation of the behavior of each model, then explore the model application to habitat use and preference by fish, using computer simulation.

MODEL BEHAVIOR

Each of three electivity factors exhibits different behavior when normalized habitat utilization and availability are evaluated over the range 0.1 to 1.0 (Figure 1). A review of the response surface of each model clearly shows the highly asymmetric nature of the forage ratio model: the index goes to infinity as utilization approaches 1 and availability approaches 0. This highly volatile behavior of the forage model index at low levels of availability could lead to erratic behavior at the tail ends of habitat suitability curves, where there may be little data. This represents a severe problem for its use in the development of habitat suitability criteria, because the electivity, or preference, of individual habitat groups (i.e., ranges of depth or velocity) are not treated independently, as forage items are in forage selection studies, but are modified in relation to the highest level of electivity (i.e., they are normalized to one). Thus, if a very scarce habitat group is found to be moderately used by fish its electivity index may be so large that it signficantly dampens the relative electivity of other, less-scarce habitat groups.

The inherent asymmetry of the forage ratio has been pointed out by Strauss (1979). It can be eliminated by logarithmic transformation, i.e., log(R/P). The log transformation (to any base) also reduces the volatility of the untransformed ratio. With a base 10 log transformation, for example, the electivity values range from -1.0 to +1.0 for utilization and availability values ranging from 0.1 to 1.0. The value of an electivity index can

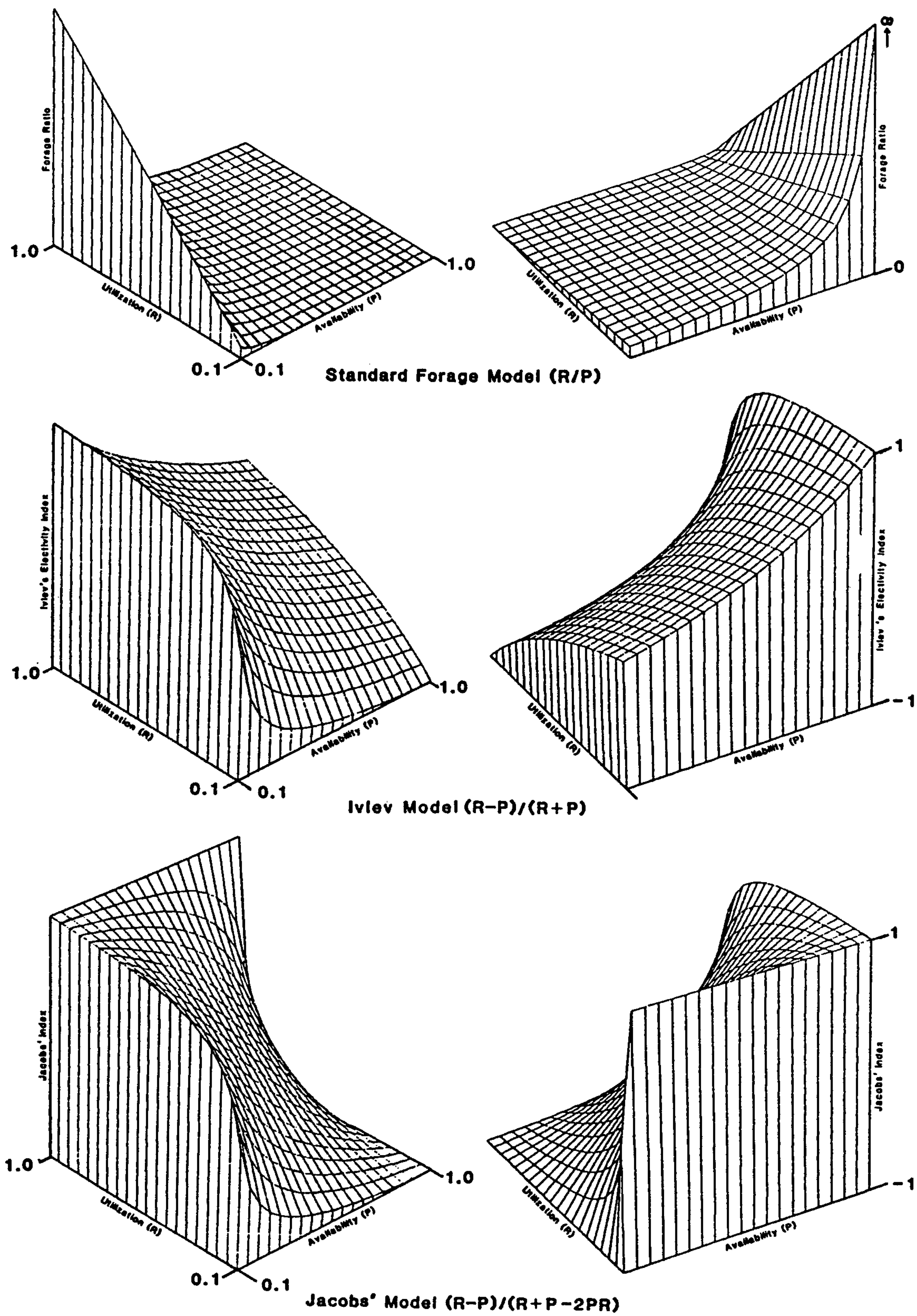

Figure 1. Behavior of the Ivlev, Jacobs, and standard forage ratio models, evaluated over the range of 0.1-1.0 utilization and availability.

nevertheless become large, approaching negative and positive infinity, as utilization and availability, respectively, approach zero. The transformed ratio has the additional disadvantage of being undefined when either utilization or availability is zero.

The Ivlev and Jacobs models, by comparison, have more-symmetrical response surfaces, and their electivity indices range between -1.0 and +1.0 (see Figure 1). This feature of the responses of these two models would make them more appropriate when dealing with data where there are likely to be small numbers of observations for certain habitat classifications. As with the standard forage model, the Ivlev and Jacobs models reach their peak electivities at the combination of high utilization and low availability. The shapes of the response surfaces are similar for the two models, except at high levels of utilization or availability. In the Jacobs model, when utilization is high, electivity is more positive; conversely, when availability is high, electivity is more negative. The element of the Jacobs model that produces these dynamics is the "-2PR" modifying term in the denominator. At low levels of either utilization or availability, the modifying term contributes little to the value of the denominator, and the resulting electivity index is similar to that of the Ivlev model. However, as the level of either utilization or availability increases, the modifying term becomes more pronounced, the overall effect being to accentuate the individual effects of utilization and availability.

MODEL EVALUATION

Throughout the use of forage-theory models as tools in the development of suitability index criteria, there has not been a clear demonstration of the validity of transferring these models from forage theory to habitat selection. Because adequate demonstrations do not exist, certain questions persist. Is it appropriate to use models that are based on a comparison of probabilities of a predator encountering a food item with the probability of finding the food item in the gut of the predator? Are there sufficiently strong similarities between the way in which an organism utilizes a food resource and the way fish select physical habitat in a stream?

To explore these questions--to test the portability of forage theory models to suitability index criterion development--we constructed a computer simulation model that describes the mechanism by which habitat features (depth or velocity) might be utilized by fish. The purpose of the modeling effort was to investigate the dynamics of the pattern of fish utilization with a constant level of available habitat and changing numbers of fish. Accordingly, fish numbers were increased in the model to the point where habitat availability became limiting. The three electivity index models were continually evaluated in terms of their ability to recover a postulated preference function. The model was programmed in Pascal for use on IBM microcomputers.

In the model, the stream was represented as a finite number of cells (15,675 cells) throughout which varying levels of a stream velocity

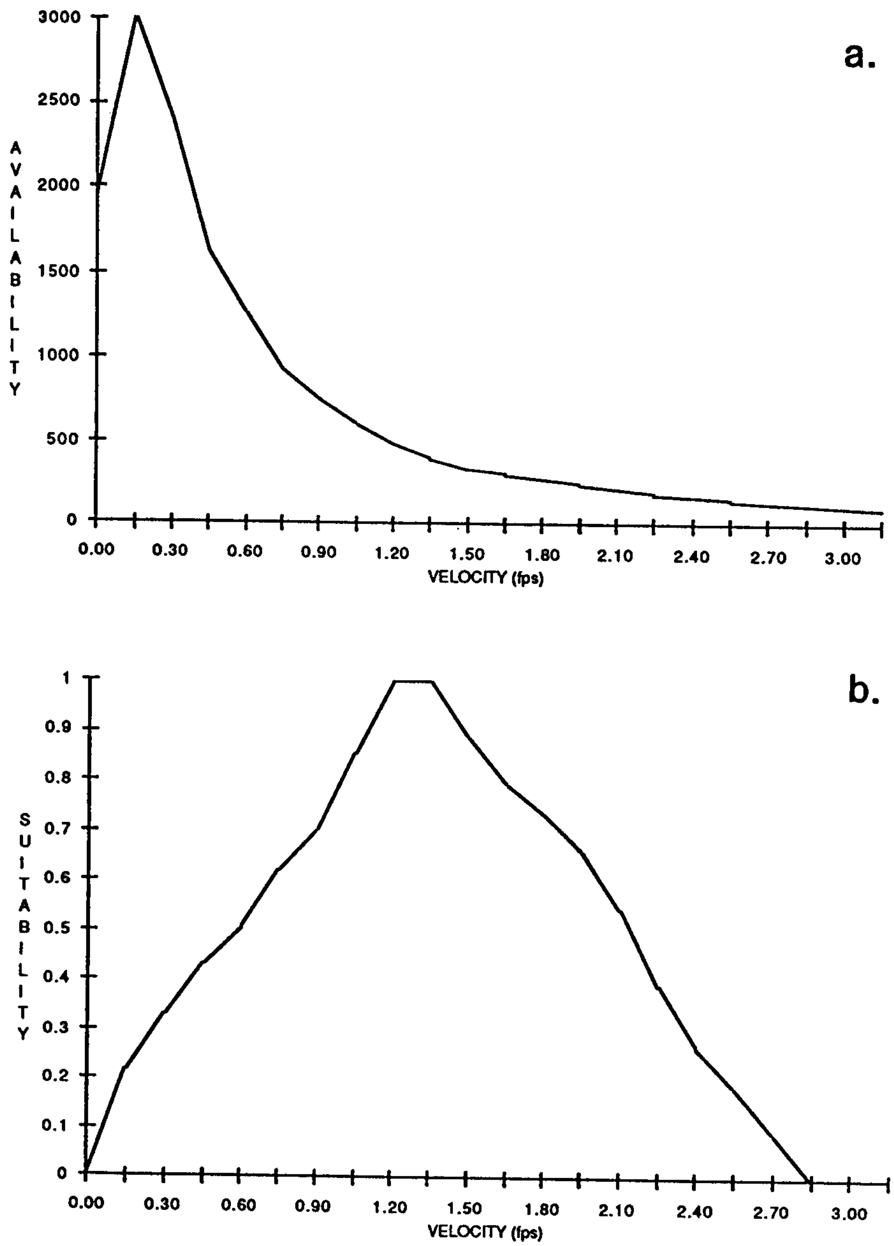

Figure 2. Distribution of available velocity habitat (a) and postulated velocity preference curve (b) used in simulation model evaluations of forage theory electivity models.

(represented in feet per second, fps) were randomly distributed. The distribution of velocity values used to represent habitat availability is shown in Figure 2a. Each cell in the stream was assumed capable of housing one fish. The one-cell/one-fish hypothesis is supported by field observations of trout, which document the existence of a finite number of focal points, or feeding stations, in a stream, each occupied by one fish (Baldes and Vincent 1969).

Into this distribution of available velocity habitat, fish populations of varying sizes were introduced. Individual fish within each population were distributed by the model into the available cells based on preferred velocity, defined by the postulated preference or suitability index function (Figure 2b). The curve used in the simulations is a preference function developed for adult rainbow trout (Bovee 1978). The habitat preference function is viewed in this investigation as reflecting natural variability in the population, with a majority of the population seeking velocities within a range of approximately 1.20-1.35 fps, and smaller percentages of the population seeking slower and swifter velocities. This variability in preferred velocity could be due to a number of factors, including variability in fish size, condition, and individual preference.

The predicted patterns of utilization associated with eight different population sizes, ranging from 1,000 to 13,000 fish, are shown in Figure 3. As long as the number of fish is small, relative to the amount of available habitat, all fish are able to inhabit their preferred habitat, and the utilization distribution matches the preference distribution. Figure 4 represents the normalized patterns of utilization for four population levels. Note that for a population of 1,000 fish, the normalized utilization pattern is identical to the stipulated preference function.

As population size increases, the number of available velocity cells becomes limiting over a certain range of velocity values. When available velocity becomes limiting, the model places fish that are unable to reside in their preferred habitat into neighboring habitat that has not become limited. At this point the distribution of habitat utilization no longer reflects the distribution of habitat preference (Figure 4). Ultimately, as the fish population continues to increase, available habitat becomes saturated, and the utilization distribution will match that of availability.

Preference distributions predicted by the three electivity index models for varying numbers of fish are shown in Figure 5. All three models fail to recover the stipulated velocity preference distribution, tending to predict much larger ranges of preferred conditions than were known to be the case, even when habitat is not limiting.

A closer look at the predicted preference functions for a single population level reveals some interesting dynamics of the different models. It can be seen from Figure 3 that for a population of 4,000 fish, velocity in the range of 1.5-2.0 fps becomes limited, with the result that each of the electivity index models predicts maximum electivity over this range. The consequence of this behavior is an overemphasis of preference in the area of limitation. While velocity in the range of limitation is preferred by a moderate fraction of the population, it is overemphasized by the models in terms of its preference by the population as a whole. This distortion of the

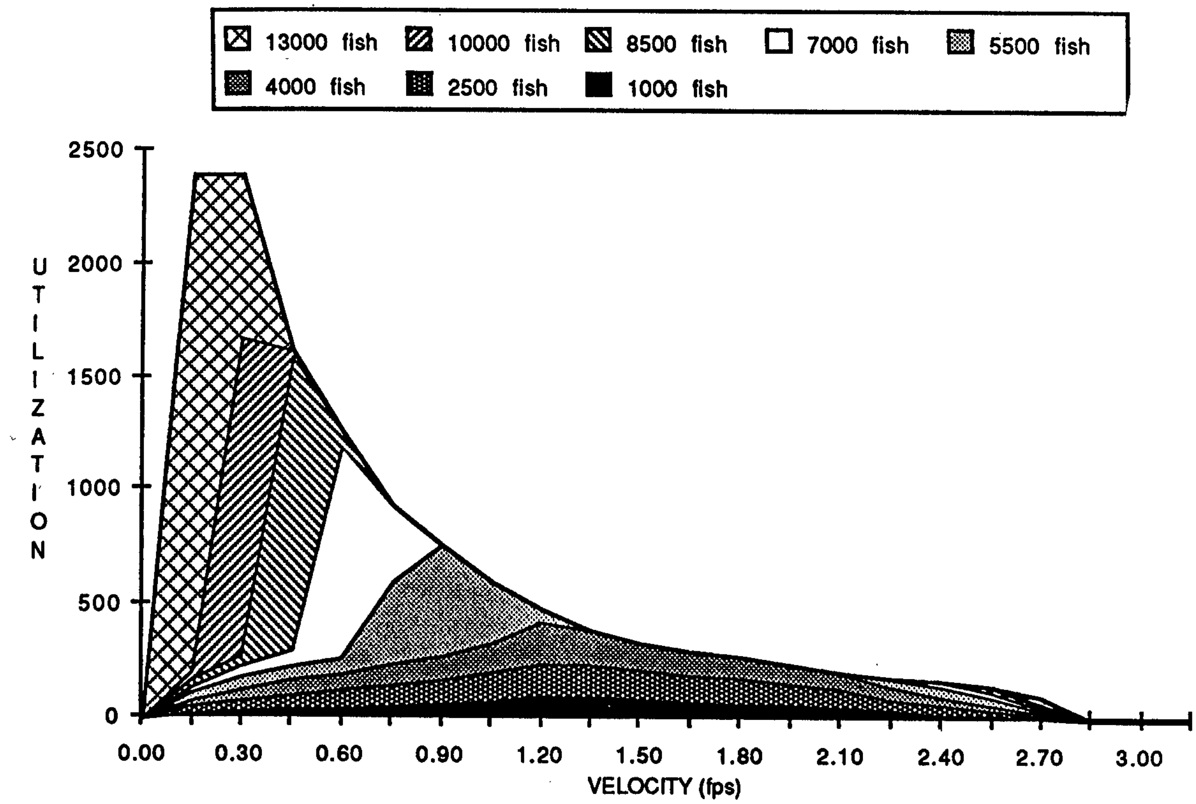

Figure 3. Predicted distribution of utilized velocity habitat for population sizes ranging from 1,000 to 13,000 fish.

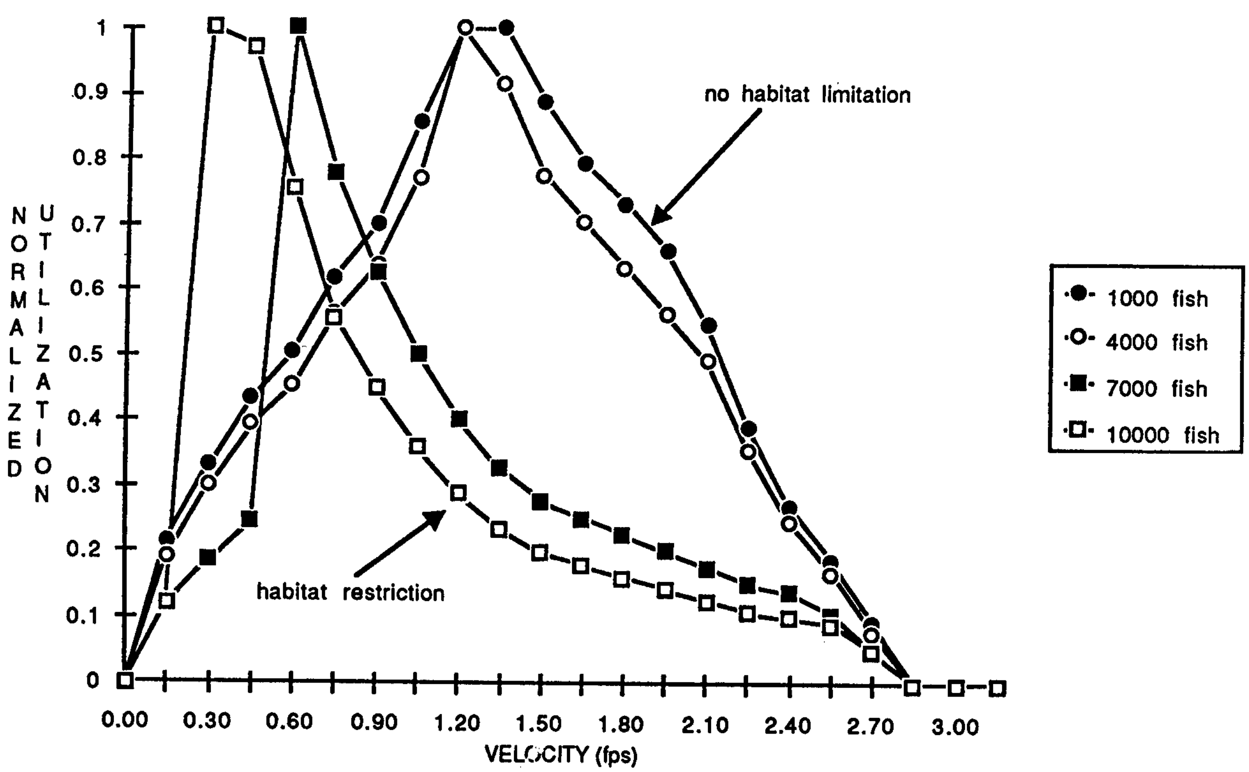

Figure 4. Predicted distributions of utilized velocity habitat for four fish population sizes, normalized to one.

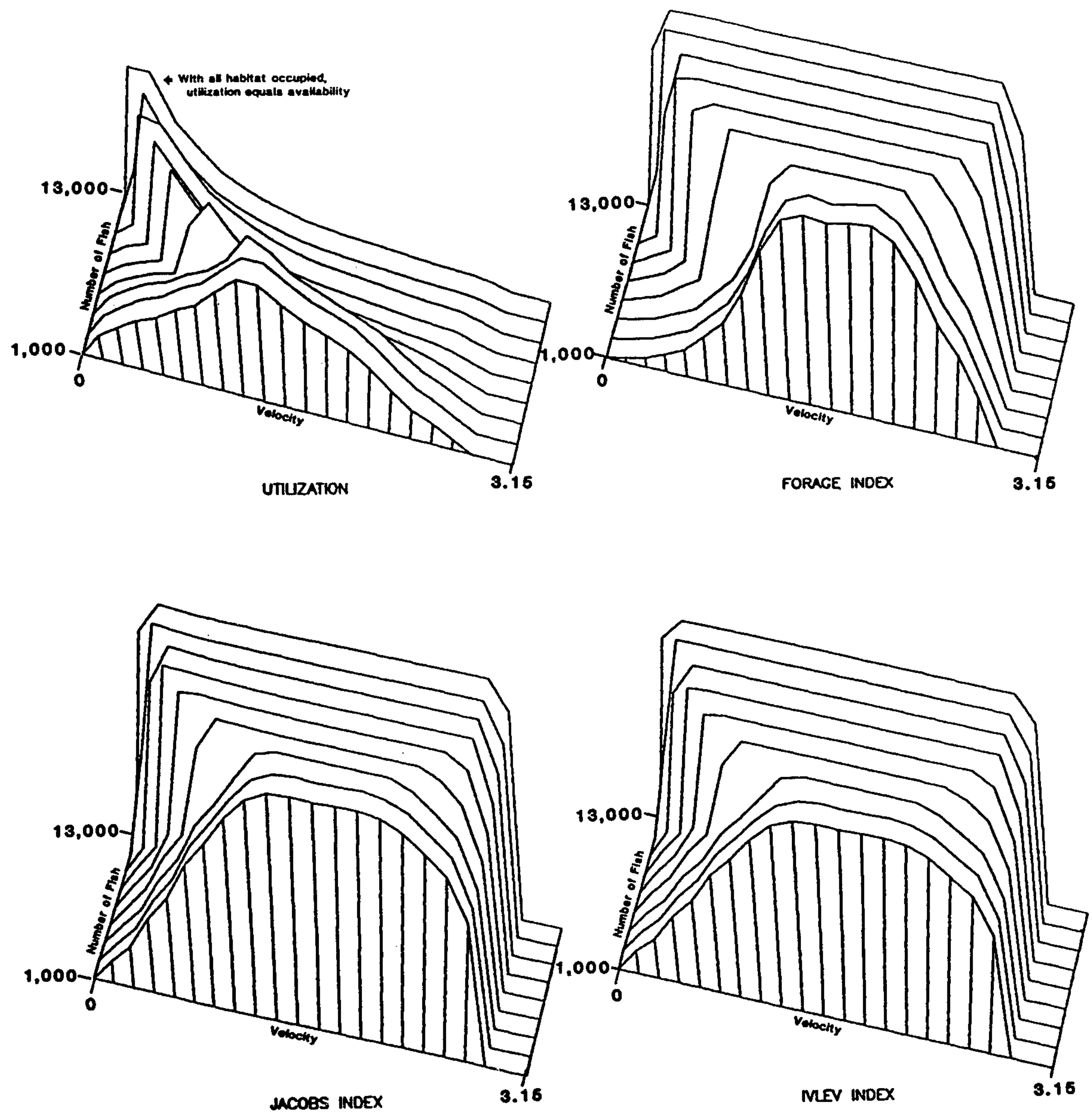

Figure 5. Velocity preference curves predicted by the Ivlev, Jacobs, and standard forage ratio models for varying numbers of fish.

preference of a limiting habitat is independent of the preference for the habitat. Thus, even swift water, preferred by a very small fraction of the population, would be assigned a preference value of 1.0 if it were limiting.

The distortion of preference in the area of habitat limitation is compounded in the forage ratio model by a concurrent depression in predicted preference at velocities where habitat restrictions are not present. This is clearly illustrated in Figure 6, where a population size of 4,000 fish is highlighted. At this population level, velocities in the range of 1.5 to 2.0 fps first become limiting (Figure 6a). The resulting preference is predicted by the forage ratio model to be 1.0 over the range of limitation, while preference values in the vicinity of 0.6 fps are simultaneously reduced to values well below the stipulated preference.

DISCUSSION AND CONCLUSION

It is clear from these results that none of the correction techniques tested work. They all fail to recover the known preference, causing distortion in direct proportion to the degree to which preferred habitat is unavailable. We conclude that unless an adequate amount of preferred habitat is available to each fish observed, the resulting utilization distribution will be a biased estimate of preference, and that the bias cannot be corrected by using the techniques reviewed.

What, then, are the differences between the manner in which organisms forage for different food items and fish select depth or velocity in streams. The fundamental distinction between the two phenomena is the number of choices making up the experimental unit. In the case of fish selecting habitat, individual fish make a single selection of a habitat type that is mutually exclusive of all other potential habitat selections. The fish selects one velocity and is observed at that velocity. In the case of foraging organisms, the individual makes multiple selections that are not mutually exclusive of one another. Here the experimental unit is the collection of multiple selections made by the individual forager or population of foragers. Hence, comparisons of differences in relative utilization and availability are an appropriate measure of the degree of selection by the forager for individual forage items. In the case of habitat selection by fish, differences in absolute amounts of utilized and available habitat constitute the proper comparison.

Can habitat preference be determined from an analysis of utilization and availability data? Based on our analysis, the answer to this question is no. The argument behind this answer is derived from an extension of the situation in which preferred habitat of a certain type is not present in the stream. When a type of habitat that is preferred by a certain segment of the population is not present (e.g., deep water), the observer lacks information that would indicate the extent to which the population prefers habitat within that range. In this situation, the observer does not know the number of individuals within the population found utilizing shallow water that are residing in preferred

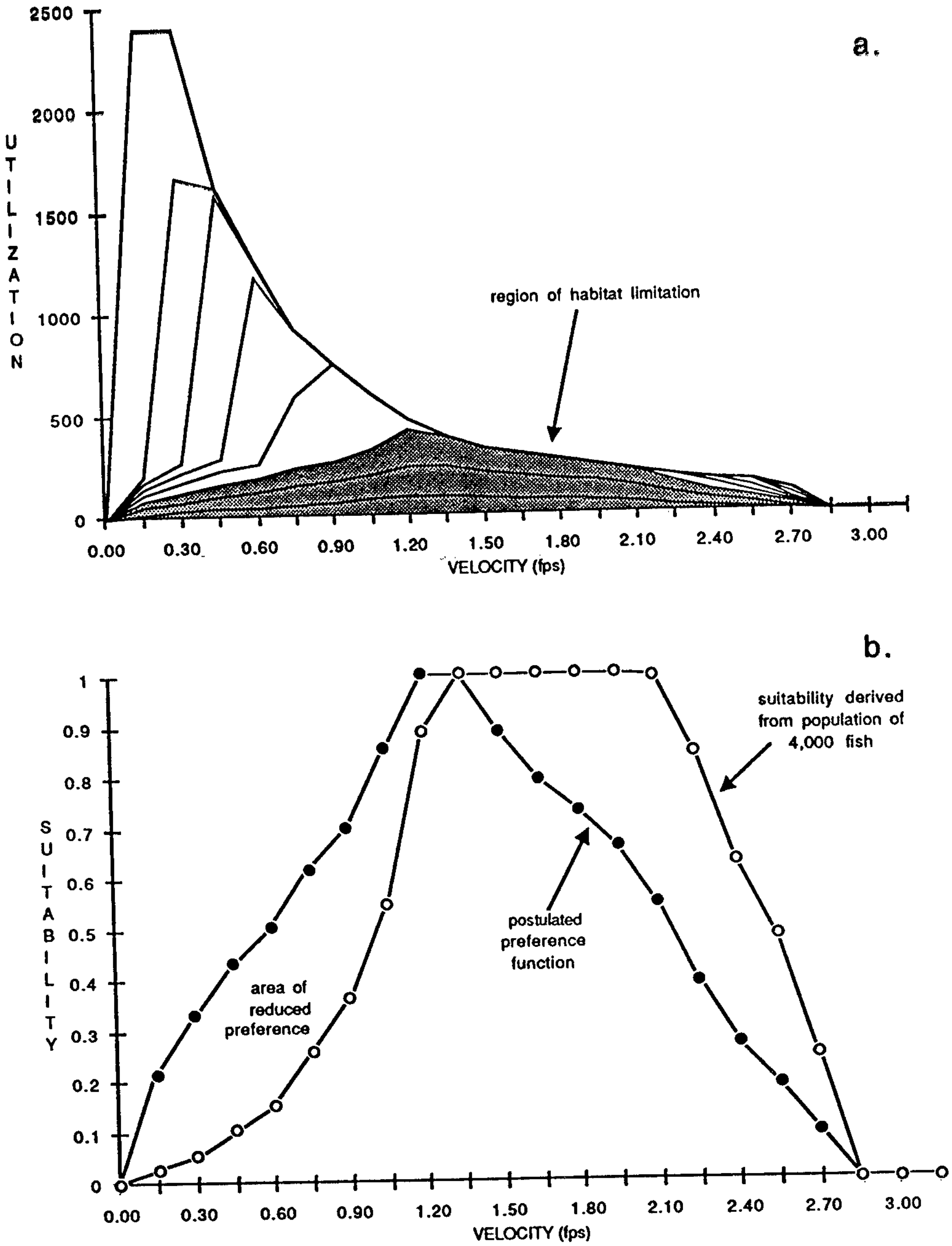

Figure 6. Predicted distribution of utilized velocity habitat for a population of 4,000 fish (a), and corresponding suitability function predicted by the forage ratio model (b).

habitat and the number of individuals that are residing in less-than-ideal habitat by virtue of the nonavailability of their preferred habitat (deep water). This same lack of information exists in a situation involving habitat limitation. When all available habitat of a given type has been utilized, the observer does not know which segment of the population found in nonlimited habitat would move into the limited habitat if it became more available.

We conclude, therefore, that if all types of preferred habitat are available to the fish being observed, then there is no need to attempt to correct the observations of habitat utilization with data on habitat availability; and if all types of preferred habitat are not available, the techniques that have been used to make this correction do not work and should not be used.

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QUESTION AND ANSWER SESSION

J. Emil Morhardt

Voos: You only allowed one fish in each cell?

Morhardt: Yes. For juvenile fish where you might have many fish in one cell, this approach may be completely invalid. We're talking about a situation where one place in the habitat supports one fish.

Voos: It seems to me that if you have a paper stream, with only so many habitats available to it, it would be inevitable that the stream would eventually be saturated by allowing only one fish per cell. Then, it would be true that the suitability functions would look like the availability functions. But, if you allowed multiple counts within those cells you'd still be retaining some of that suitability in there.

Morhardt: Well, the idea is to decrease the size of the habitat units to a size small enough so that multiple fish won't fit in them.

Voos: This conflicts directly with the work I did. I was able to recover the suitability functions, with the same kind of Monte Carlo-type simulation.

Morhardt: Was it true for juvenile fish too?

Voos: Well, they were paper fish, following the same simulation approach you used, but allowing multiple fish per cell. It was a Monte Carlo simulation. I wasn't assuming a particular life stage or species.

Morhardt: The idea of stacking was included?

Voos: I think I allowed multiple fish in cells.

Morhardt: I think if you do that then you'll get different results.

Voos: You filled up all your available niches by allowing only one fish per niche with any kind of suitability function. It seems to me that eventually you should saturate the habitat, and then the only thing you could get would be the availability function.

Morhardt: I agree.

Voos: This result may be due to the way you're putting the fish in there. If you allowed more than one fish in a cell because it's more preferred, then you should still be able to recover that suitability function, even though the availability function is a completely different shape.

Milhous: That's basically the equivalent of having infinite habitat cells, which is what Dr. Morhardt was talking about. It's like allowing multiple fish per cell by assuming infinite habitat. It would still fill back up. When you put more fish in the space than it can hold, which is the way it was done here, you match the case of infinite space relative to the number of fish you have. You can put a large number of fish into one cell, but there should be a limit. If you limit what you put in the cells, as long as it's finite, I suspect you'll end up with the same results that Dr. Morhardt presented.

Campbell: I'm not going to comment about the simulation methodology you used, or paper fish, or anything. But you won't get any arguments from me about dividing utilization by available habitat. We've conducted the same type of correction with real fish and it still doesn't work. What happens is that the tails of the available habitat, where there are very few observations, really bias the results of the preference function.

Morhardt: But that's a product of the asymmetry in that simple division process.

Campbell: I've seen the same phenomenon in a variety of data. Sometimes, the preference function actually becomes a bimodal type of thing.

Smith: I think that's more a problem of sample size and sample error though. I've experimented with different electivity indexes and taken subsamples of larger sample sets that I have. The anomalies, or whatever you want to call them, out on the X-axis limb, are more evident and more influential with small samples. As you increase your sample size, the gaps fill in and things start to smooth over.

Campbell: But the fact remains that in any stream, there are limited amounts of deep, fast water. If you had the total universe available to pick from, that's one thing. But there are limited amounts out there, and it tends to be shown on the tails of the distribution.

Smith: Not necessarily. An appropriate smoothing mechanism can reduce the influence of those outliers.

Morhardt: Ron, what have you been using? Have you just been using utilization curves or how have you been dealing with it?

Campbell: I've been struggling with coming up with preference curves. I've been working on it for 3 years and I haven't had the final answer yet. We've used utilization curves for site-specific information and if you're going to transfer the information to another stream, then you should go to the effort of creating preference criteria. In a site-specific situation, we normalize all the size and class interactions of the fish, all the species composition, and substrate composition. The fish are where they are, and I think utilization is good enough for site-specific work.

Smith: I think you're right.

Bovee: Just a note on the way we've handled that particular problem in the Instream Flow Group. I am very suspicious of utilization data, particularly when you're trying to transfer from one stream to another. As far as I'm concerned, utilization data are tremendously biased, because they are so heavily influenced by what's available. On the other hand, we are also aware of the problems associated with the forage ratio approach. The rule we've used is that the preference function should look something like the utilization function. It should be like a subset, skewed one way or the other, of the utilization function. If it doesn't look anything like the utilization function, then they're probably both wrong.

Campbell: Do you impose any kind of minimum correction zone? I mean, how different is different enough to reject the criteria?

Bovee: Let me give you an example. We received some criteria data on juvenile channel catfish a while back. The velocity utilization curves that we developed were monotonically decreasing with a peak at zero velocity. The velocity preference curve was monotonically increasing and peaked at 3 feet per second. The utilization function went one way and the preference function exactly the opposite direction. I don't have any rules on what is alike enough and what is different enough, but when you get something like that where they cross each other you have a legitimate reason to suspect both curves. We went back to the old Category I technique and looked through the literature about where you're likely to find juvenile catfish. The literature suggests that the most likely place to find them was in the fastest rapids you could find in the stream. So, the preference function matched the description that we got in the literature much better than the utilization function did.

Morhardt: I'm certainly not arguing that utilization data is the end of it. I'm just saying that we don't know what the problem is when you're dealing with natural populations.

Cheslak: I think there's one point you have to look at here. That is, you have a data set that has tails to it, and if you allow one percent of your data to govern 90 percent of your curve, you're crazy.

Comment from the floor: I think from your comments you may be overlooking a point. There are several different ways to combine use data and availability data. The people studying utilization have been doing it for a lot longer than habitat. If you look at the critiques of those indices and descriptions of their statistical properties, it might be incorrect to assume that there is only one correct preference function. You can see that they have different characteristics, given the same data set. Some go to infinity, some go to 1, some go to minus 1, etc. I think it's important to understand its characteristics.

Morhardt: The cental part of this paper is that the information to make that correction does not exist in those two pieces of information. Relative availability and relative utilization do not contain the information necessary to determine preference. I don't care what kind of correction factor you use, it won't work.

Comment from the floor: I'm not saying that, but how do you even know it worked? Maybe there isn't a correct preference function.

Morhardt: Well, it's just like Ed Cheslak did in his paper. I stipulated the data to start with and for the purpose of the model, I know it's right.

Sheppard: I tend to agree with what Ken Bovee said, that utilization and preference should really match. The problem that I had with your original assumption is that if you put enough fish in there, the availability curve will be completely filled. But dynamically, you know that there are some situations where fish couldn't physiologically, physically exist, whether its velocity or depth, because they just won't be there. Instantaneously, you might be able to create that theoretical condition, but in reality, it's not close to the preference.

Morhardt: It'll never get there. The point is that the utilization curve would be somewhere between the preference of the fish and the availability of habitat.

Sheppard: We've all read that organisms will expand out into marginal habitat, but we're trying to figure out what it is that makes a good fishery resource, and the parameters that go into it. How much you can compromise those conditions and still keep the fishery resource there. You've got to keep that in the back of your mind. That's where we're all going, because that's where the agencies are going. I appreciate all these theoretical arguments, but the bottom line is that the real organisms don't behave like theoretical ones. For example, you can bring a hatchery truck up to a stream, pour tons of fish in, and instantaneously fill all the available habitat, right? But pretty soon there'll be a sorting out. In a matter of minutes, hours, days, weeks, until you got back down to whatever was really the carrying capacity. So, I think that some of these theoretical cases are interesting, but I think it's just not totally realistic.

Comment from the floor: Another point following that same line is, how often are your preference curves developed in a situation where you're over carrying capacity? I would assume that most preference functions are developed when you're under carrying capacity.

Morhardt: You don't have to be at carrying capacity. You just have to be at a point where some of the fish can't go where they really want to go. As soon as you reach the point where any fish can't find a place it wants to go, then the utilization function will start moving toward the habitat availability function. The problem is you don't know where you are on the curve. So I think if you want to find out, you have to do an experiment. You can't just go out and look at a natural population. Take all the fish out of the stream or set up an artificial stream, and then put one fish in and see where it goes. Then you can find out what they're really doing, but you can't do it by going and looking at a natural population.

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16. Abstract (Limit: 200 words)

Reliable habitat suitability criteria are critical to the successful implementation of the Instream Flow Incremental Methodology (IFIM), or any other habitat-based evaluation technology. Habitat suitability criteria are the characteristic behavioral traits of a species (relative to the selection of optimal habitat) that are established as standards for comparison in the decisionmaking process.

This proceedings is a compilation of 22 papers presented at a workshop in December 1986. The objective of the workshop was to obtain insights into problems and possible solutions to criteria development, from the perspective of professionals closely involved with the subject. Five workshop sessions dealt with (1) aspects of study design and how they can influence the outcome of a study, (2) techniques for developing criteria from professional judgment, (3) field data collection procedures, (4) methods of converting field data into curves, and (5) field verification studies. Each presentation was followed by a recorded discussion period, which was later transcribed and appended to the end of each paper.

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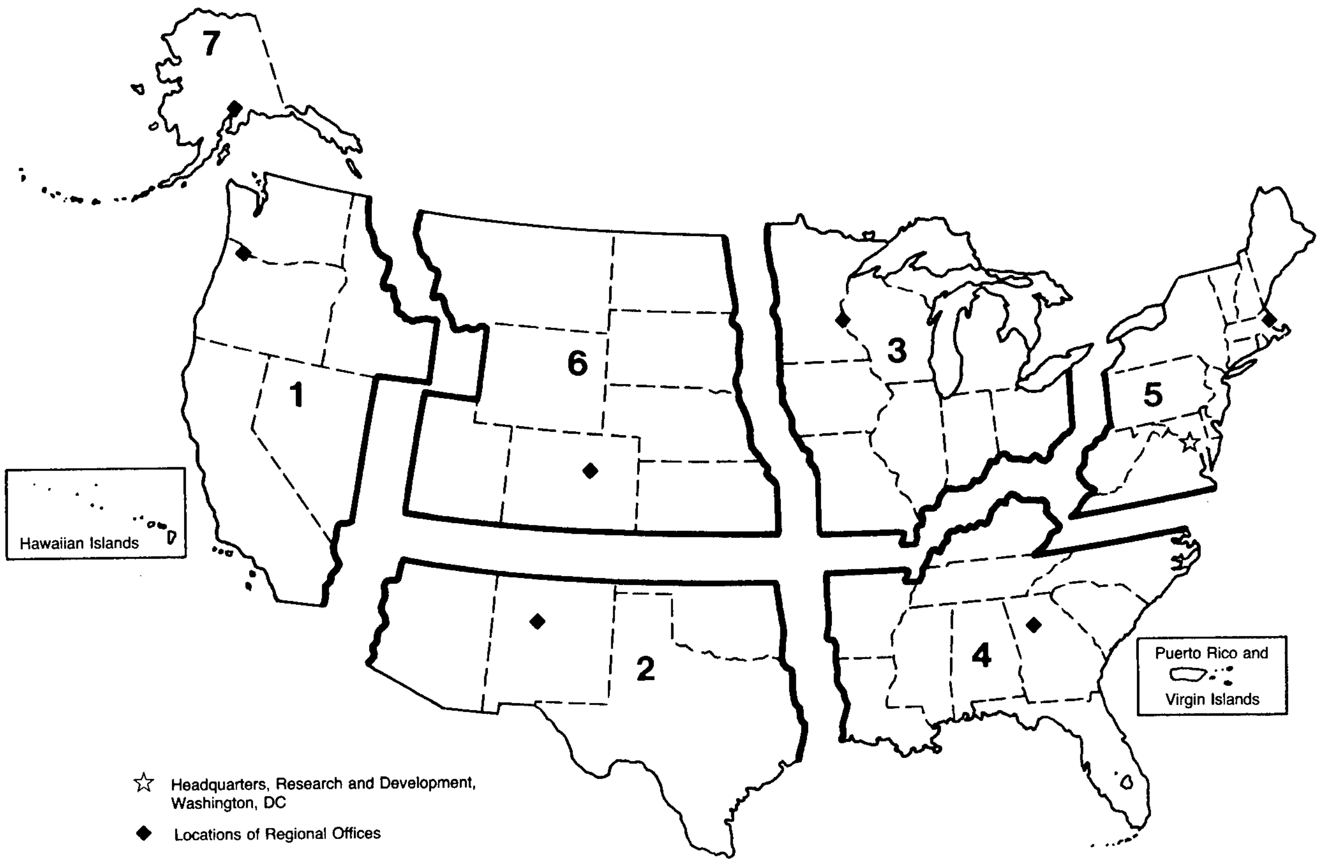

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